Scintillator Strip ECAL optimization

13th November 2013

K. Kotera,
Shinshu University

Contents

1. Why we develop the strip scintillator ECAL in CALICE.
2. Strip scintillator ECAL in ILD.
3. Basic performance evaluated by test beam experiments.
4. Further optimizations:
5. Summary.

Why we study Sc-strip ECAL

1. Requirements:

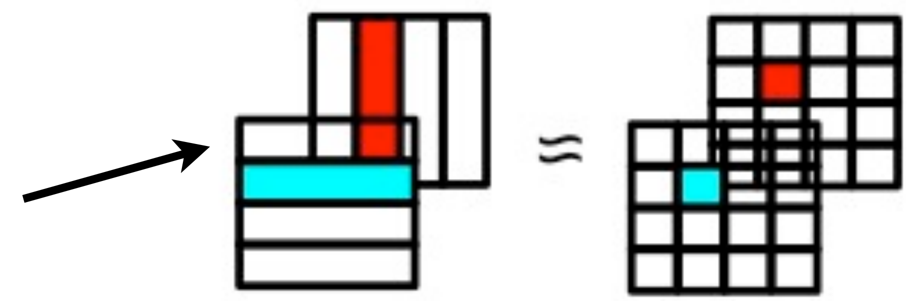
   5 mm x 5 mm lateral granularity,

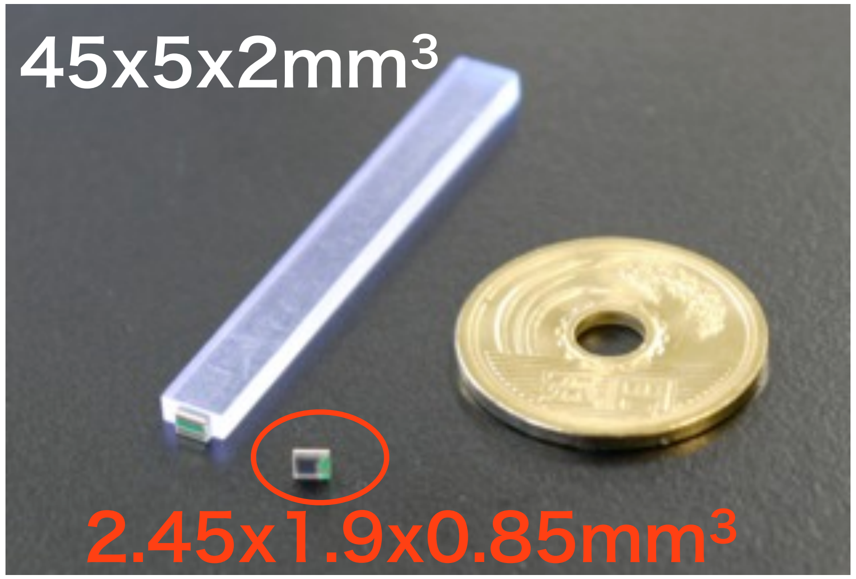
   robustness for ~ 10^8 channels.

2. Development of SiPM(MPPC) is still active, providing additional possibilities extremely high granular calorimetry: small package, increasing dynamic range, ...

3. Idea of strip segmentation;

   the strips in odd layers are aligned orthogonally to those in the even layers. channels $10^8 \rightarrow 10^7$

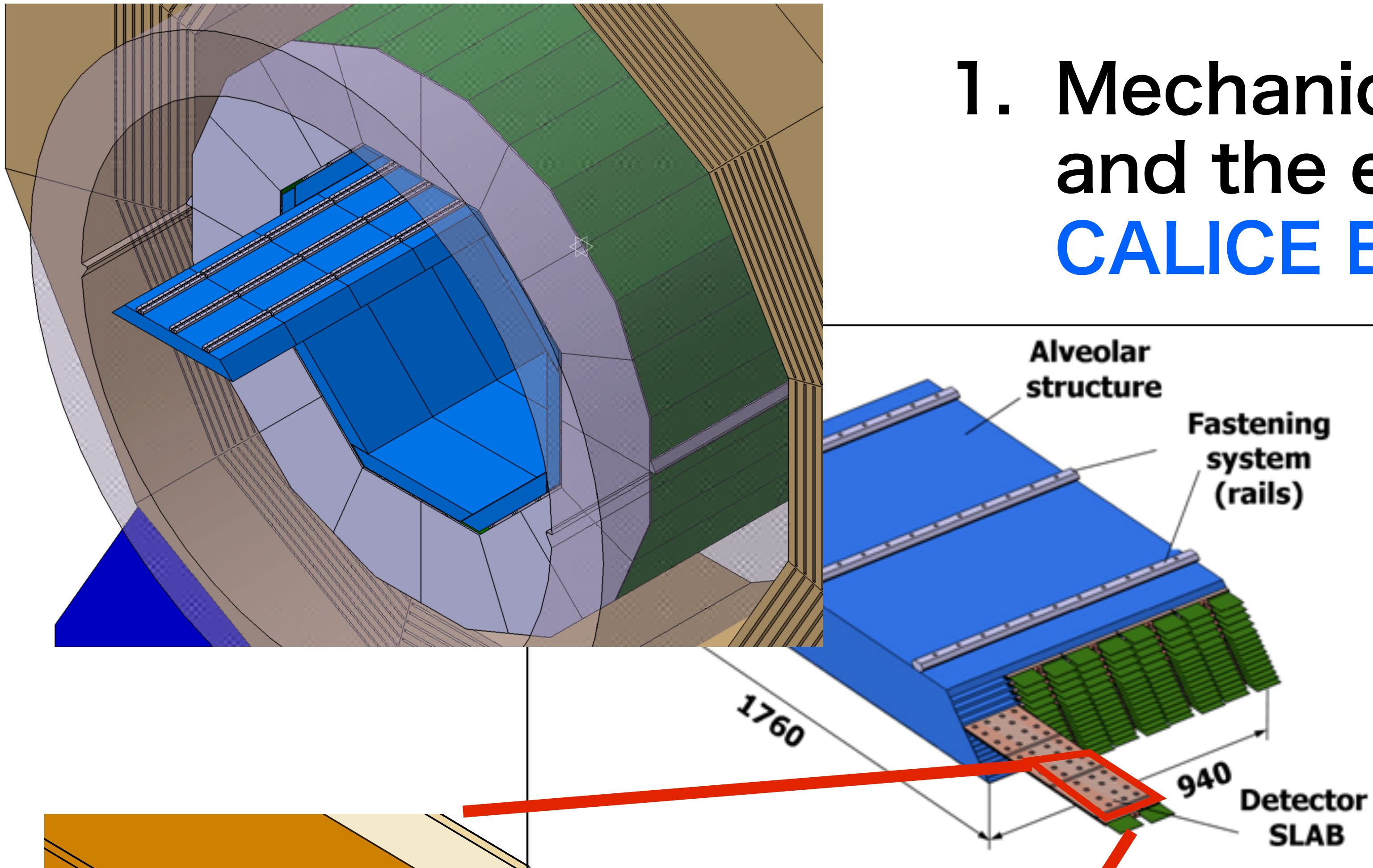




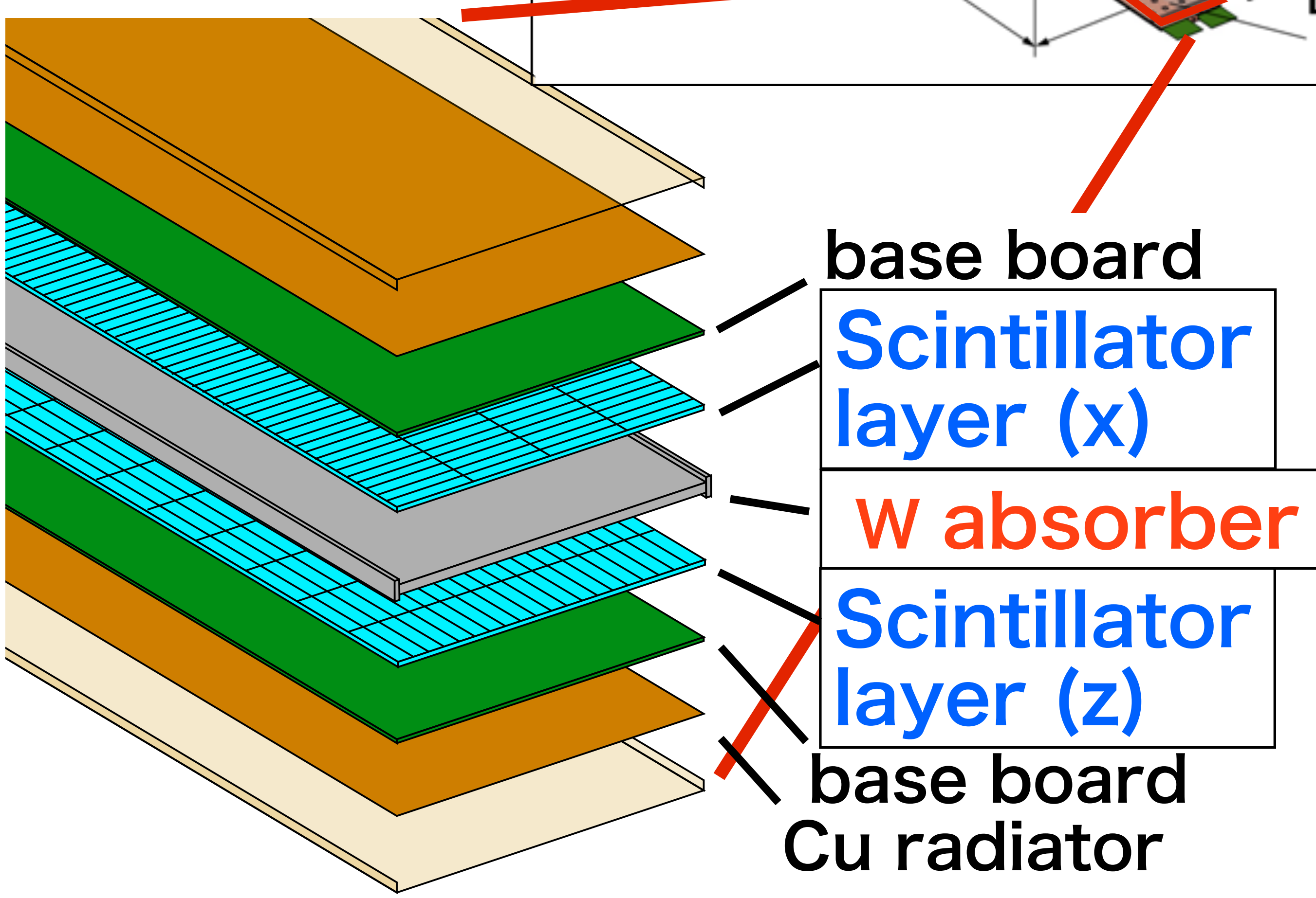
4. Timing measurement with resolution < 1 ns.

   ▶ long lived heavy new particle

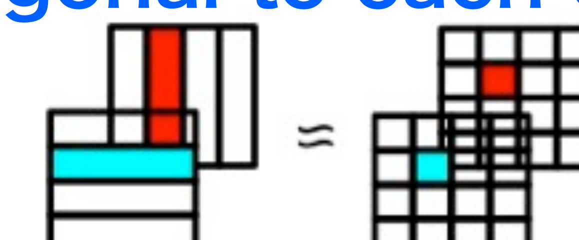
Strip ScECAL in ILD



1. Mechanical design of the barrel and the endcaps is developed by CALICE ECAL group.
2. alveolar structure itself is made with W absorbers.
3. layer structure for the scintillator sensors.

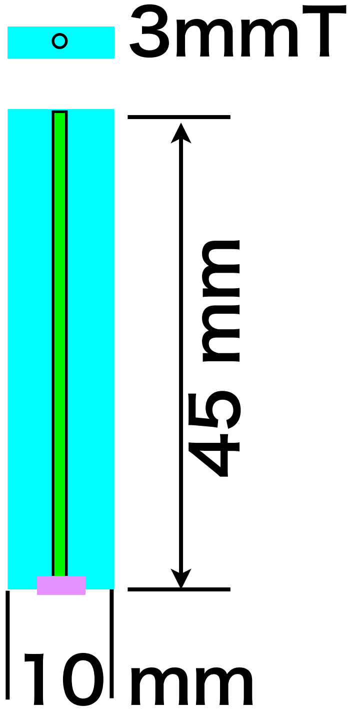


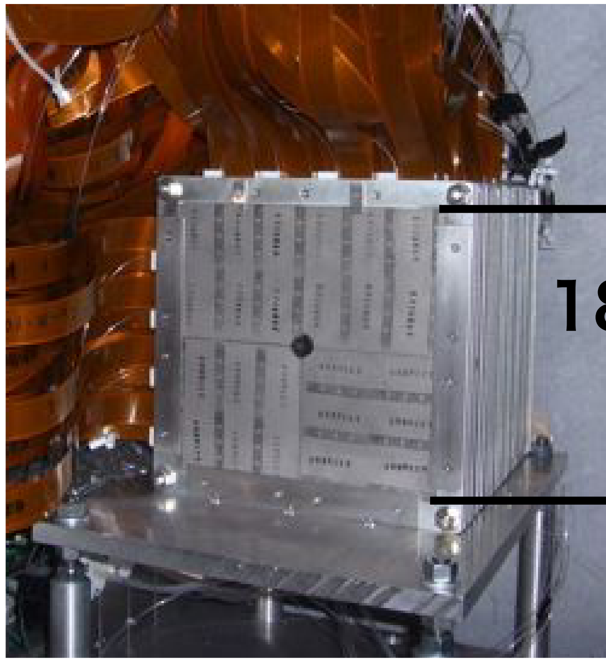
4. two scintillator layers in an alveolar make a sandwich structure with a tungsten absorber.
5. strip directions are orthogonal to each other.



Physics and technological prototype

Physics prototype





180x 180mm²

x30 layer
2160 chs

Test beam at FNAL 2009

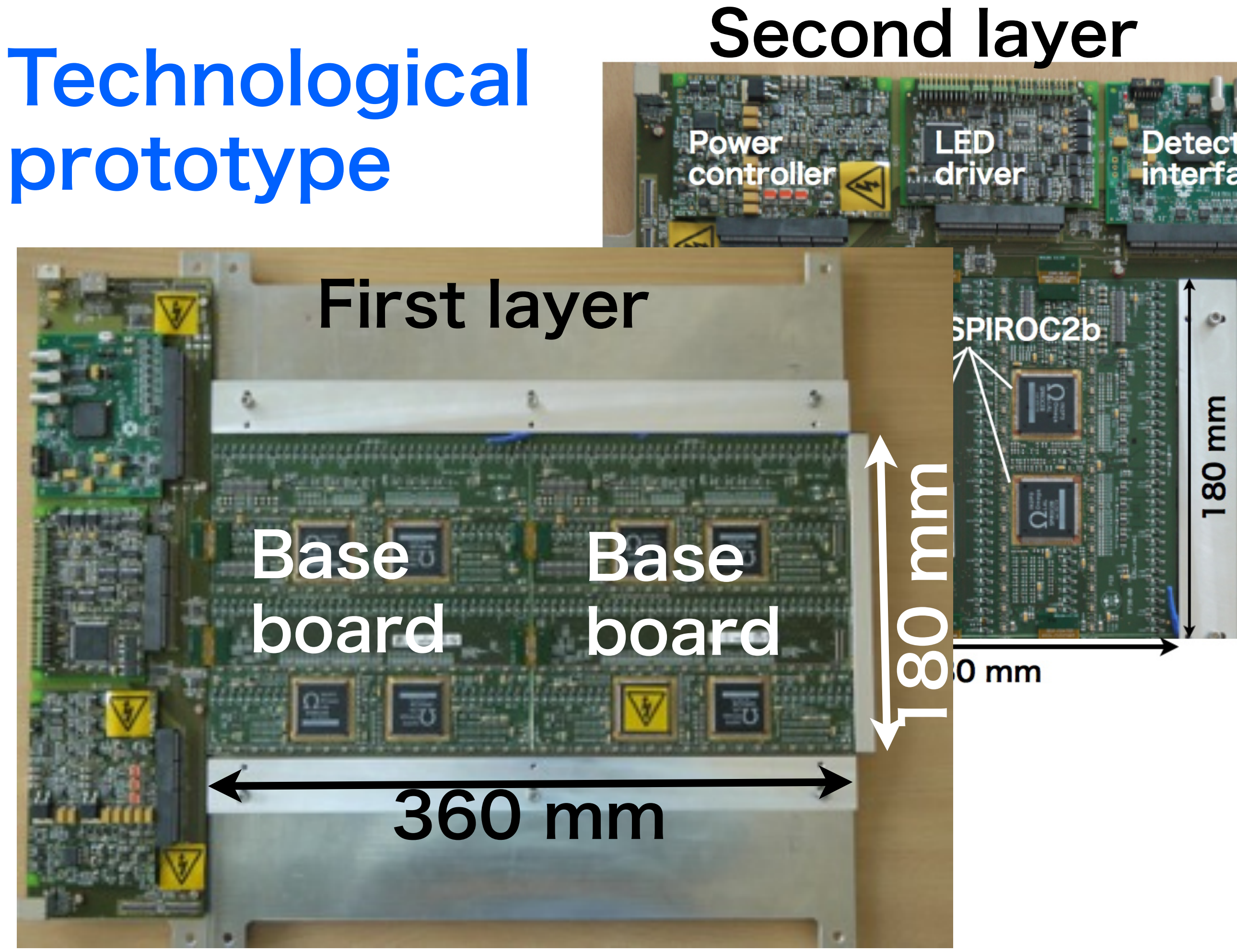
Energy resolution (σ_E/E) 2 - 32 GeV e^-

$= (12.9 \pm 0.4/\sqrt{E} \oplus 1.2^{+0.4}_{-1.2})\%$

Max deviation from linear < 2%

need to implement this system into real ILD-ECAL.

Technological prototype

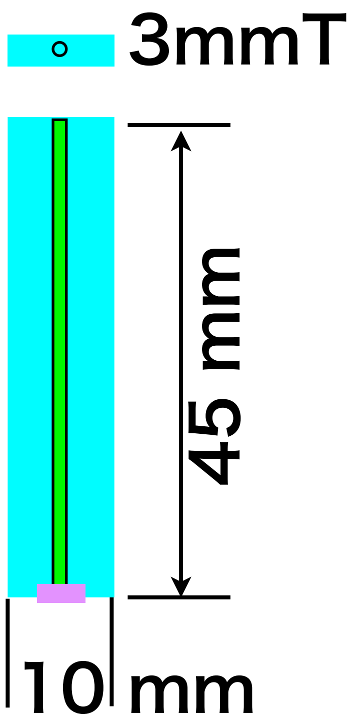


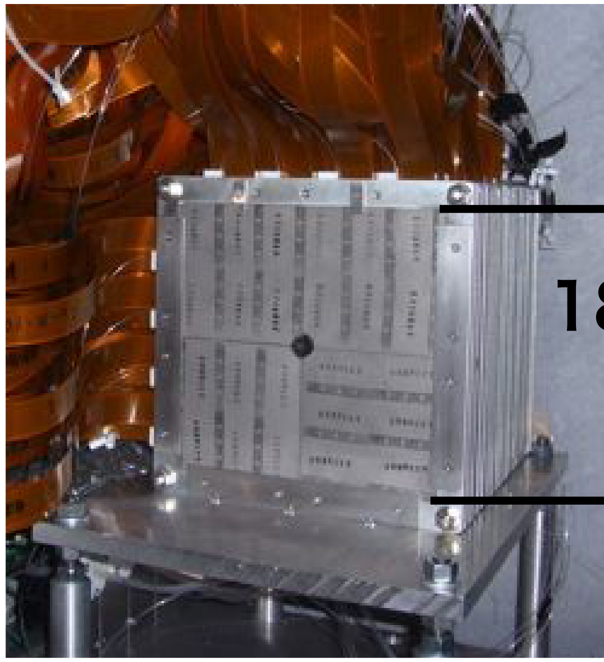
Test beam at DESY 2013

$45 \times 10 \times 3\ mm^3$ ▶ $45 \times 5 \times 2\ mm^3$

Physics and technological prototype

Physics prototype





180x
180mm²
x30 layer
2160 ch

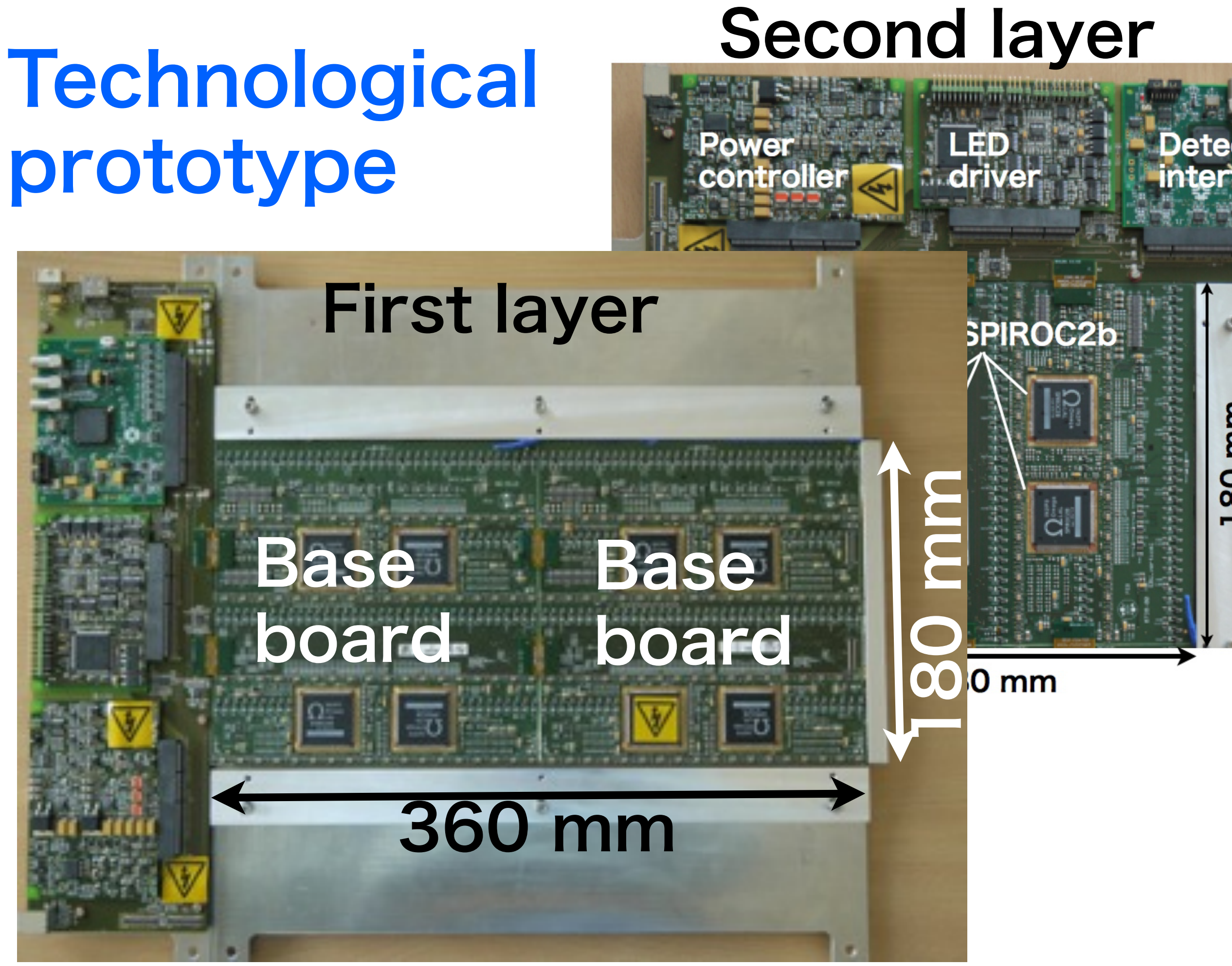
Test beam at FNAL 2009
Energy resolution (σ_E/E) 2 - 32 GeV e^-

$= (12.9 \pm 0.4/\sqrt{E} \oplus 1.2^{+0.4}_{-1.2})\%$

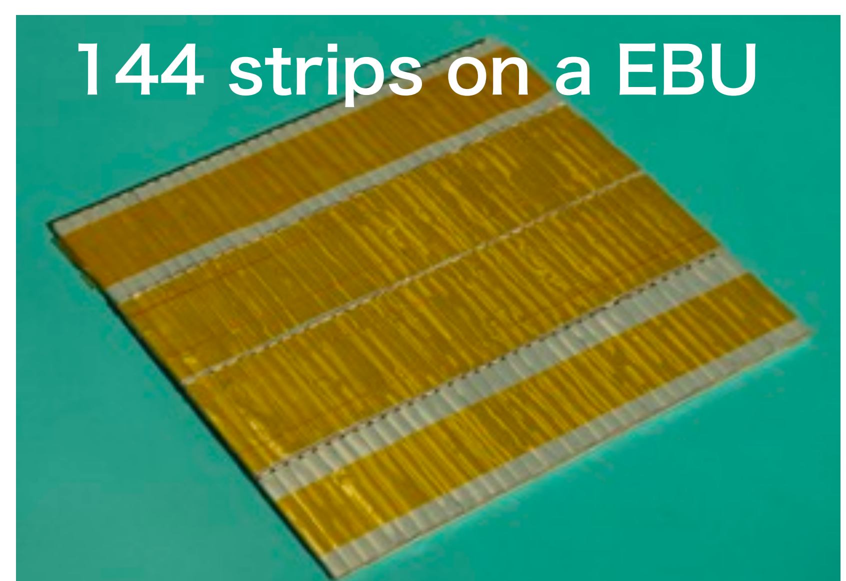
Max deviation from linear < 2%

need to implement this system
into real ILD-ECAL.

Technological prototype

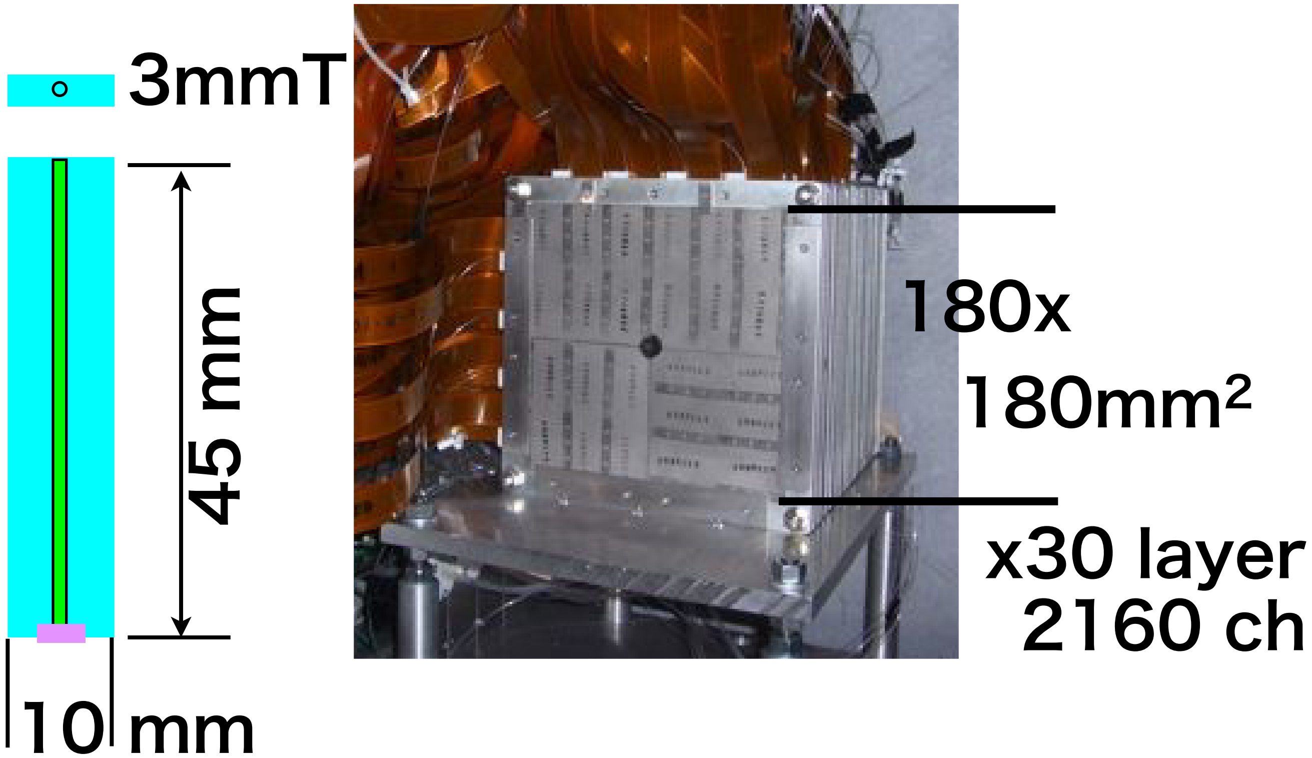


144 channel/(180x180mm²board)
Test beam at DESY 2013



Physics and technological prototype

Physics prototype



Test beam at FNAL 2009

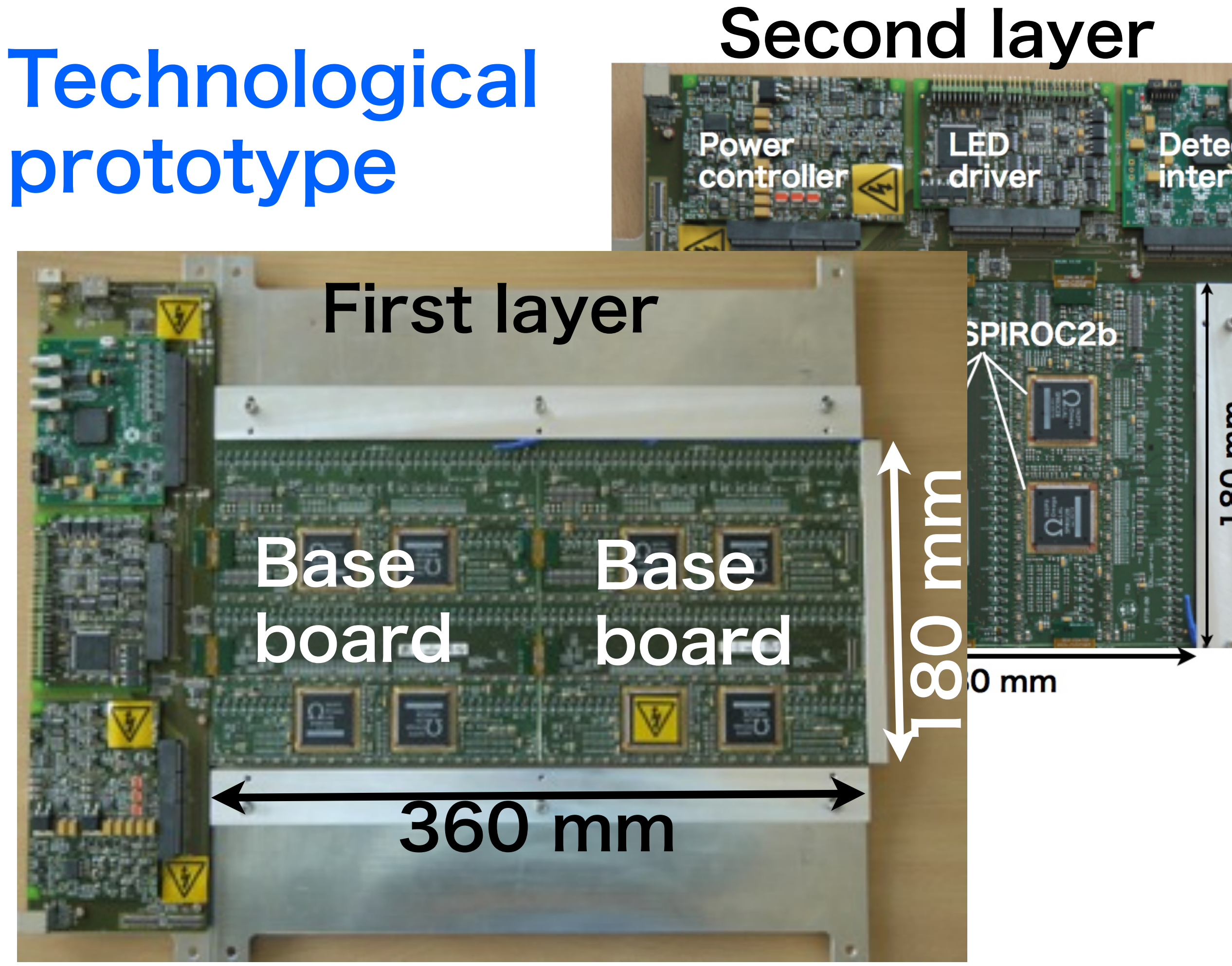
Energy resolution (σ_E/E) 2 - 32 GeV e^-

$= (12.9 \pm 0.4/\sqrt{E} \oplus 1.2^{+0.4}_{-1.2})\%$

Max deviation from linear < 2%

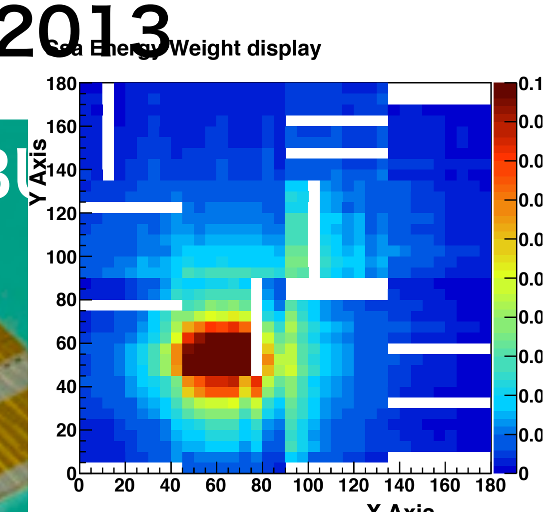
need to implement this system into real ILD-ECAL.

Technological prototype



144 channel/(180x180mm²board)

Test beam at DESY 2013



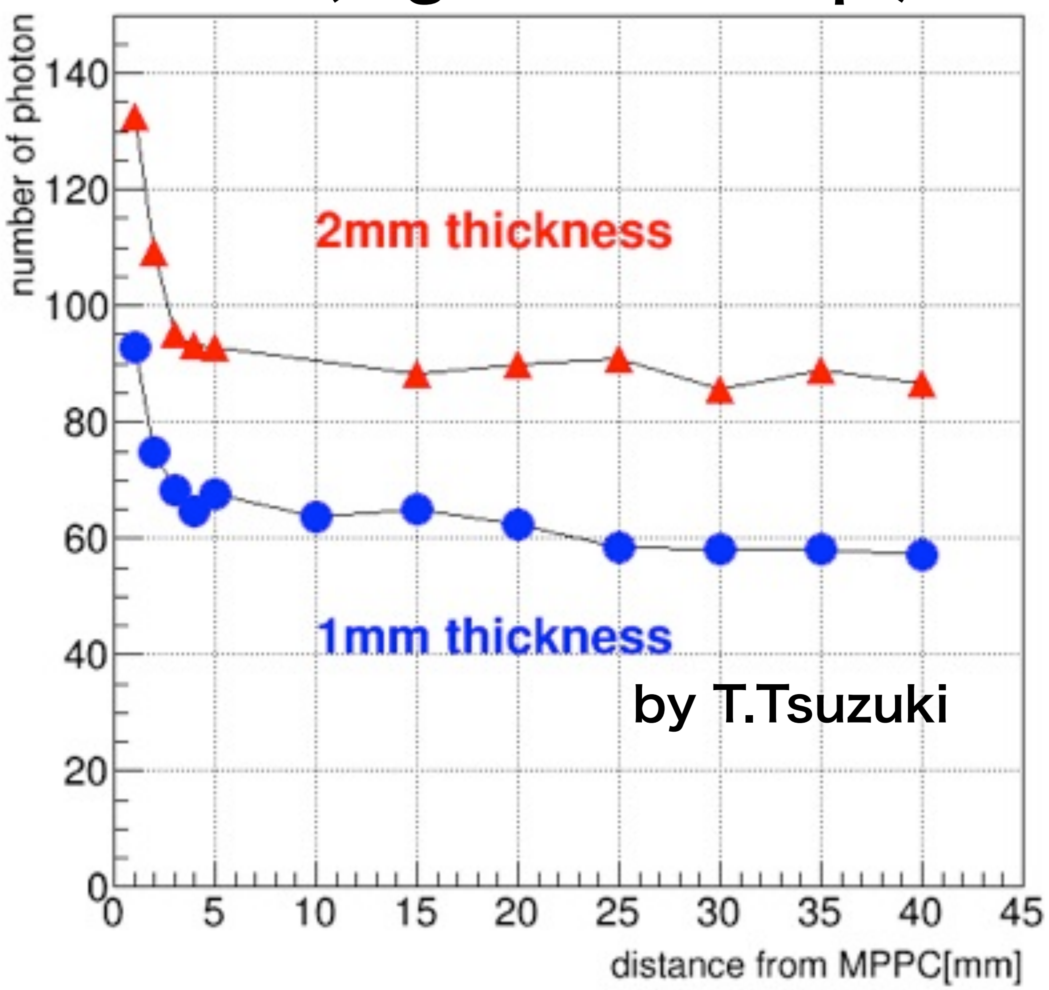
5x5mm² seg

Detail ▶ T. Ogawa's talk, after the next

Further optimization (1) :thickness of Sci.

Thickness 2mm▶1mm,
Module thickness decreases ▶ Cost of magnet is reduced.

MC(agree with Exp.)



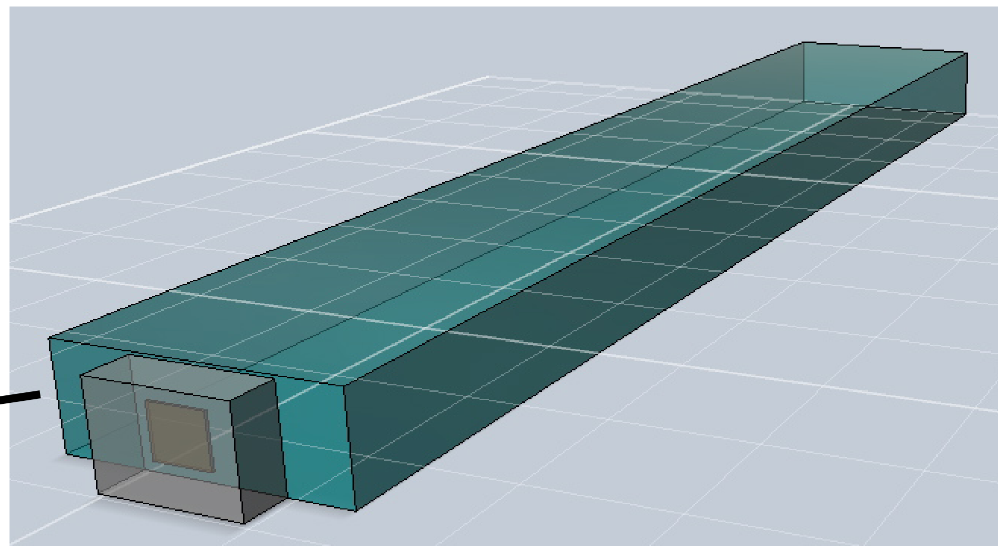
- Photon yield is required larger than 7 p.e.),
- Current design 45x5x2mm³, has ~ 7 p.e. yield at DESY TB
- 1 mm thick scintillator has photon yield factor 2/3

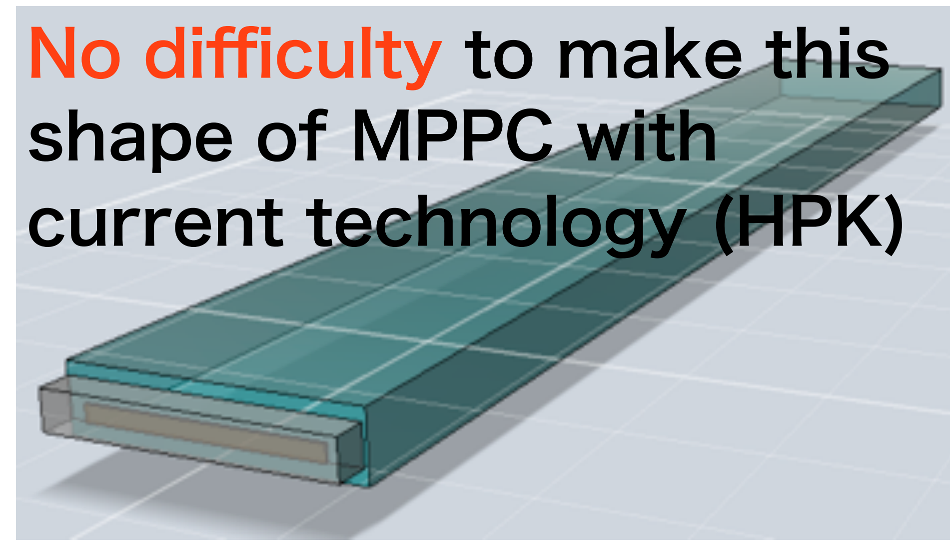
▶ need more p.e.

Further optimization (2) :Shape of MPPC

In order to increase photon yield

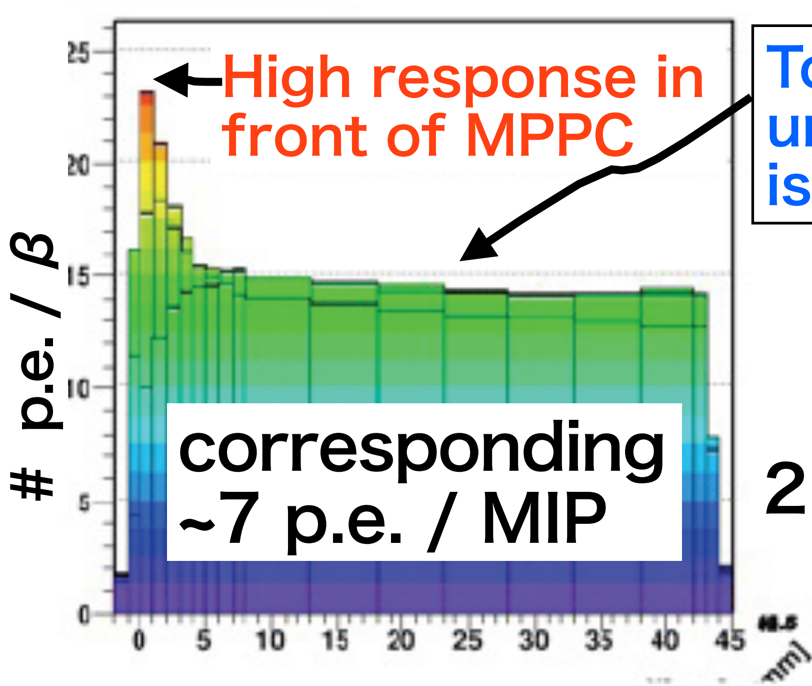
- MPPC sensor area 1x1 mm^2 ▶ 0.25 x 4 mm^2 for 1mm thick scintillator,





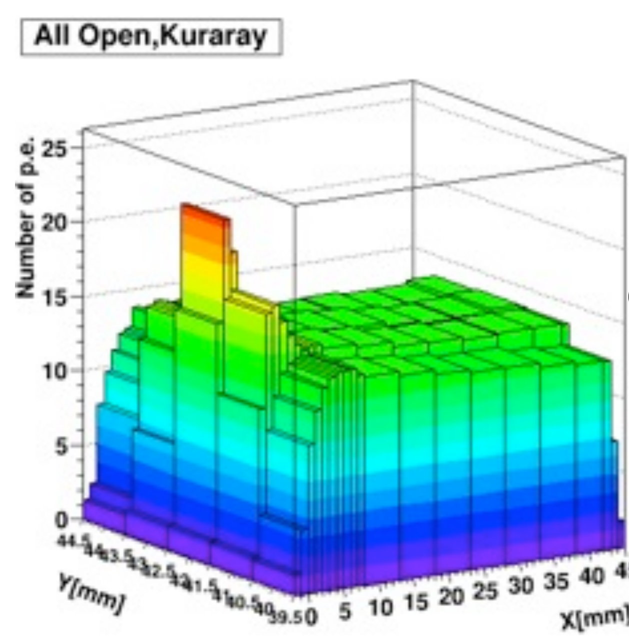
1x1mm^2 sensor:1mmT scintillator = exactly same hight
▶ acceptance loss, 0.25x4 mm^2 increases acceptance.

- uniformity without WLS fiber,

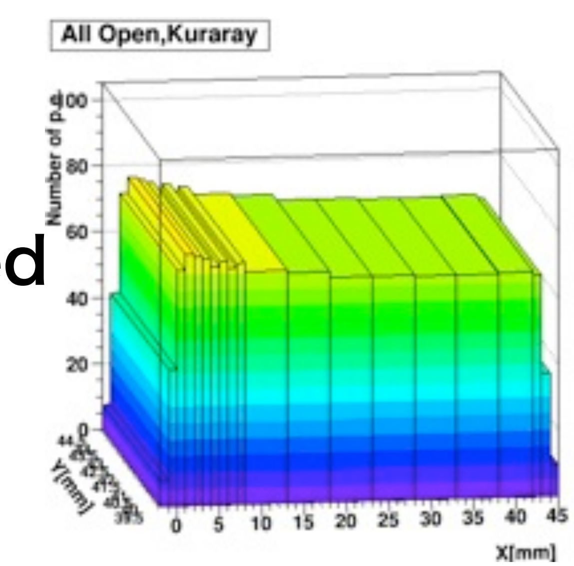


Total
uniformity
is OK

2 mm T



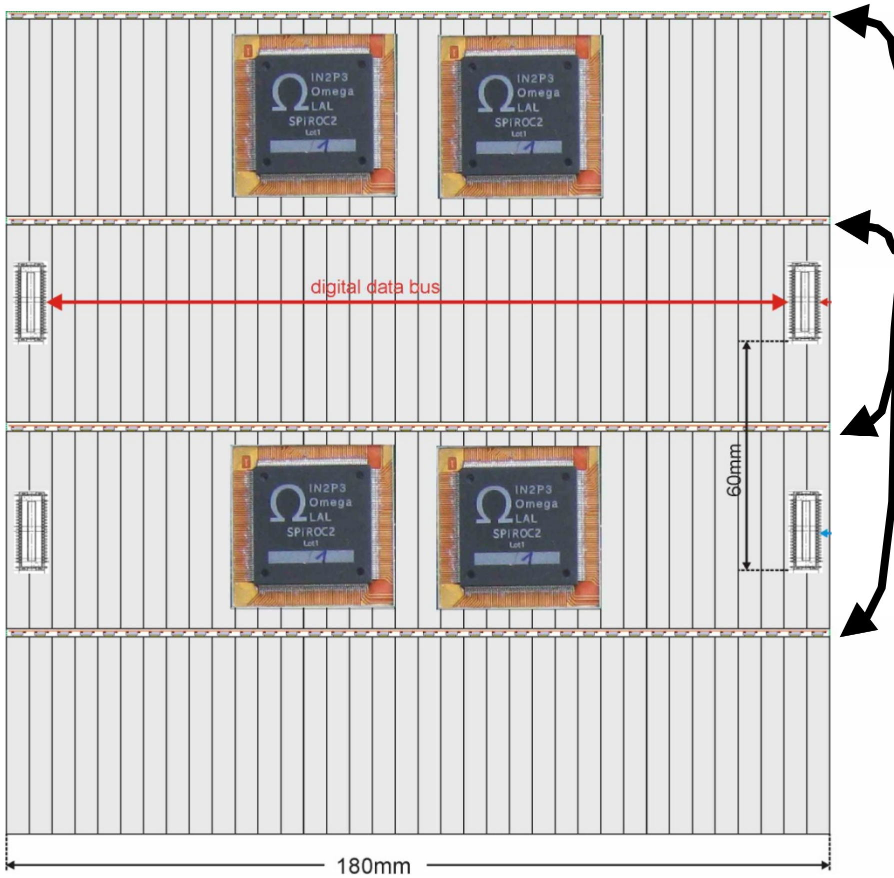
expected



by T.Tsuzuki

Further optimization (3) :position of MPPC

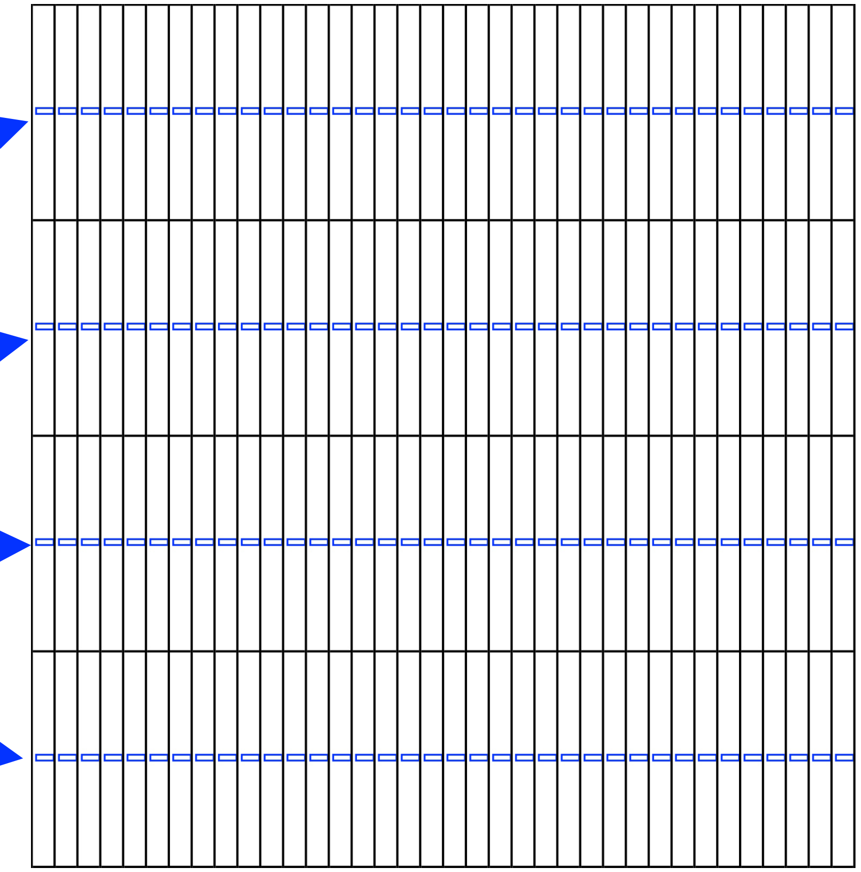
EBU (current design)



MPPC ladder
on edge

MPPC ladders
make dead volumes

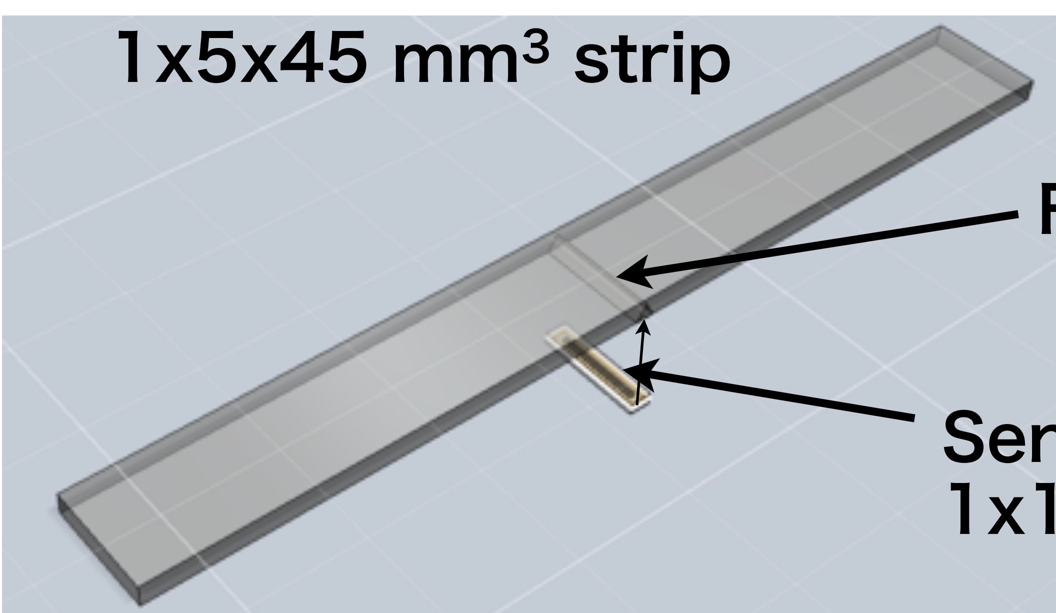
EBU (bottom readout)



MPPC ladders
no dead volume

Stable MPPC

From the bottom



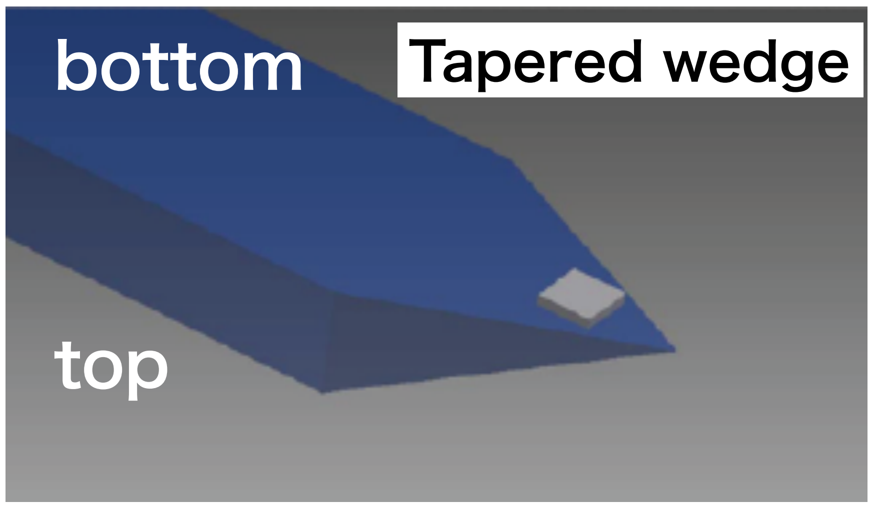
Frosted dimple
Easy procedure

Sensor area
1x1mm^2 ➡ 0.25x4mm^2

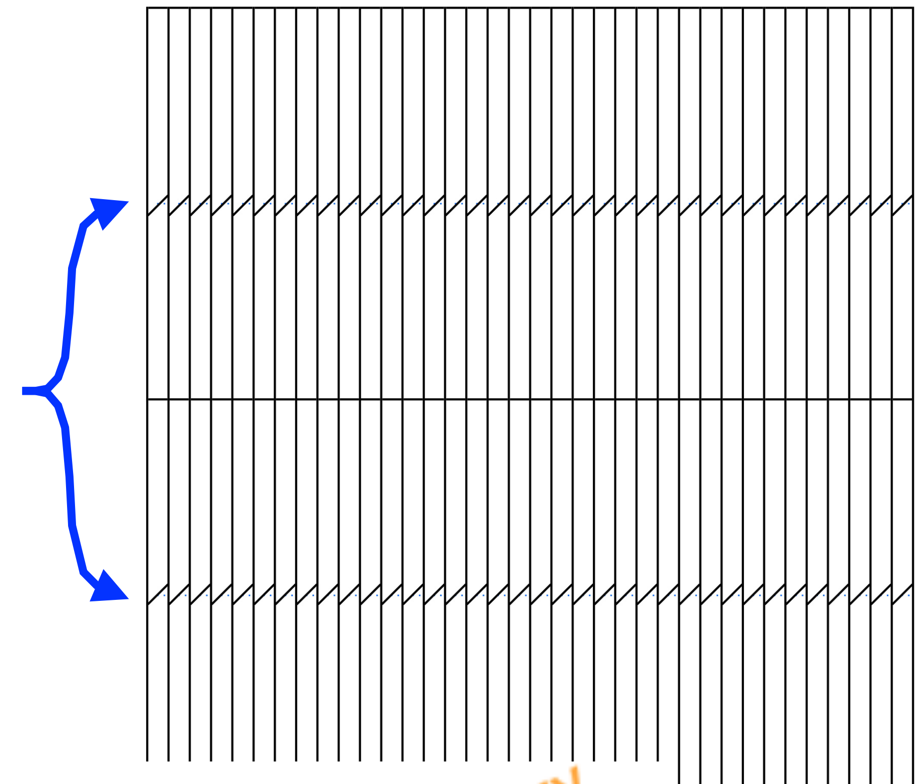
Further optimization (4) :Method of light collection

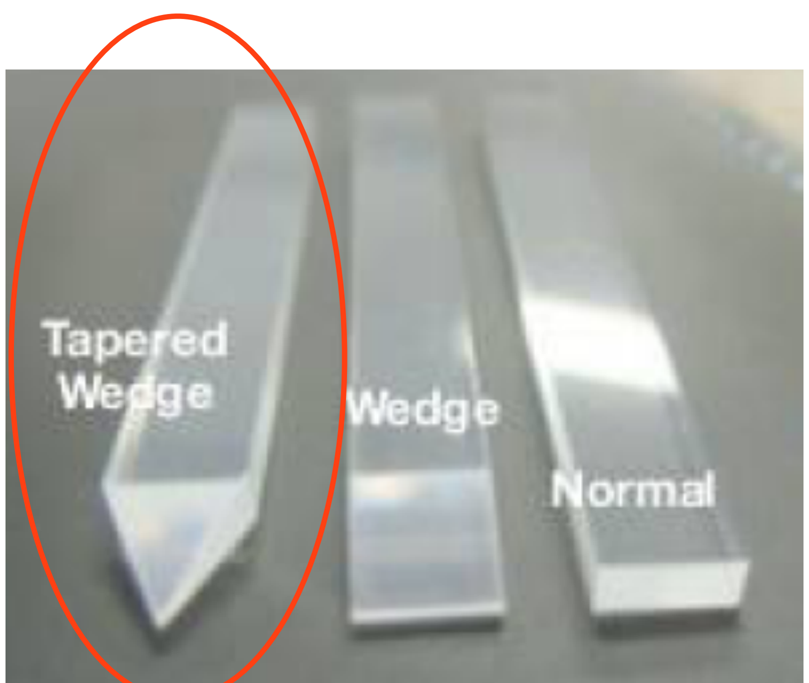
From the bottom with wedge

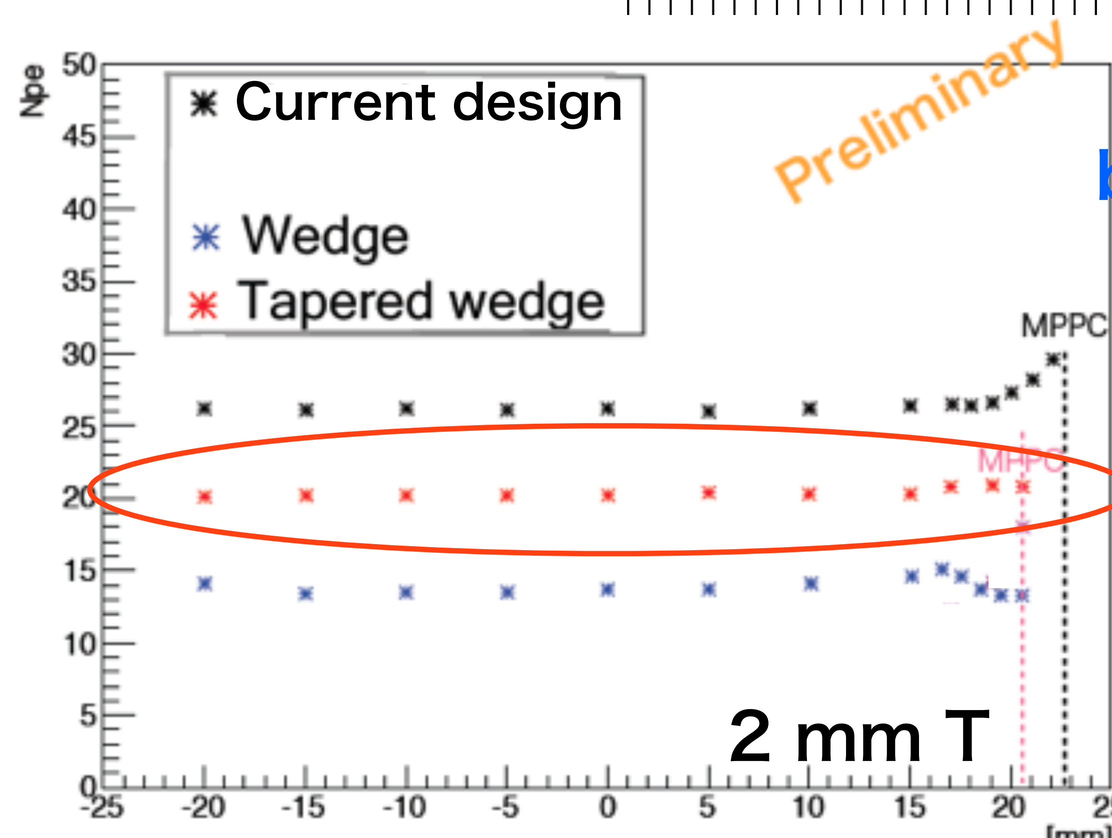
by W. Ootani,



no MPPC ladders on edge, no dead volume of MPPC







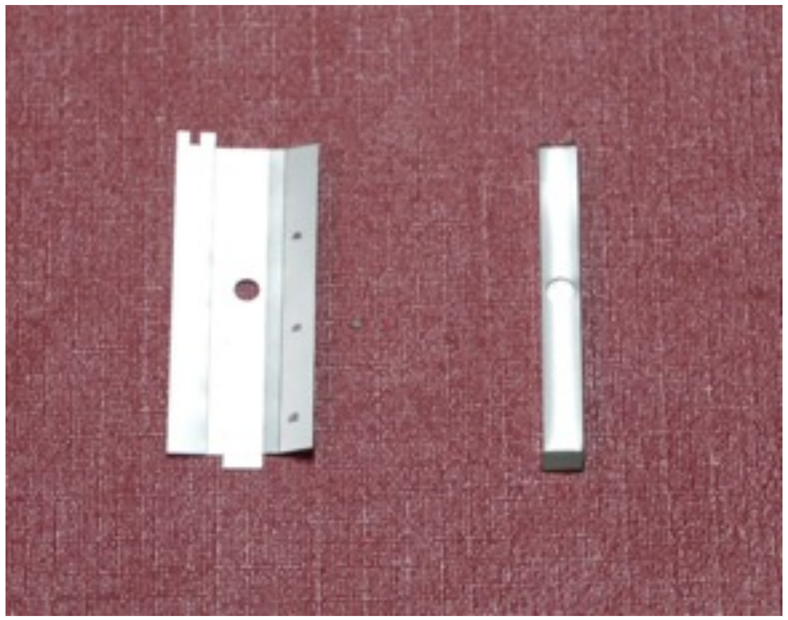
by S. Ieki

good photon yield and uniformity

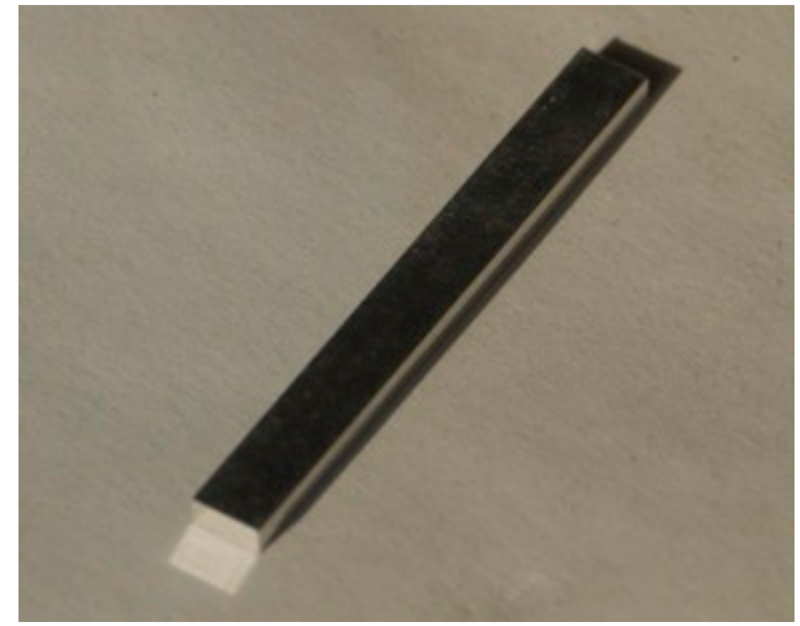
Detail ▶ next talk by S.Ieki

Further optimization (5) :reflector

Reflector film

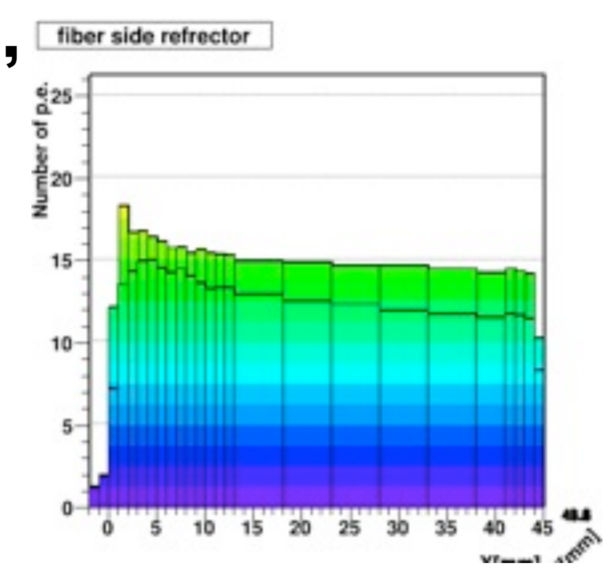


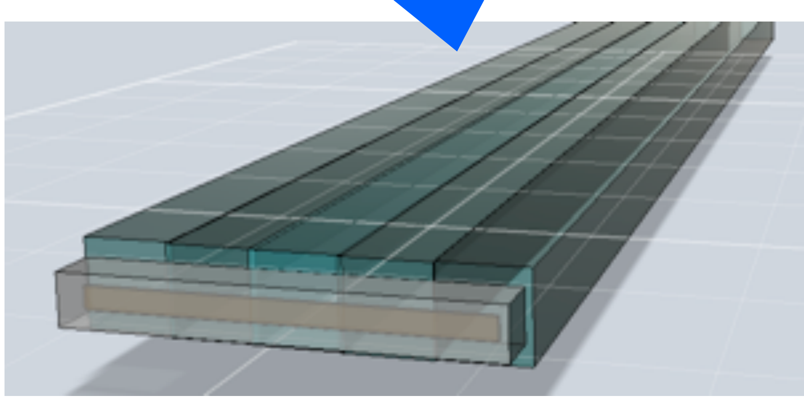
Spattering



- Already enough reflection,
- a little complex procedure to make,

- help easy construction,
- Thin layer aluminum spattering ☹
- With 200 nm silver alloy,
  ▶ongoing,





Another idea

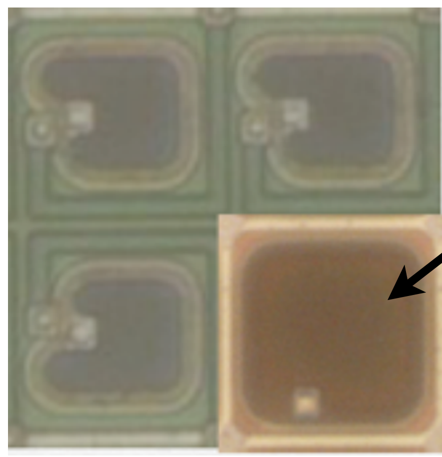
- We can use bundled clad fibers with long shape MPPC

Further optimization (6) :N pixels of MPPC

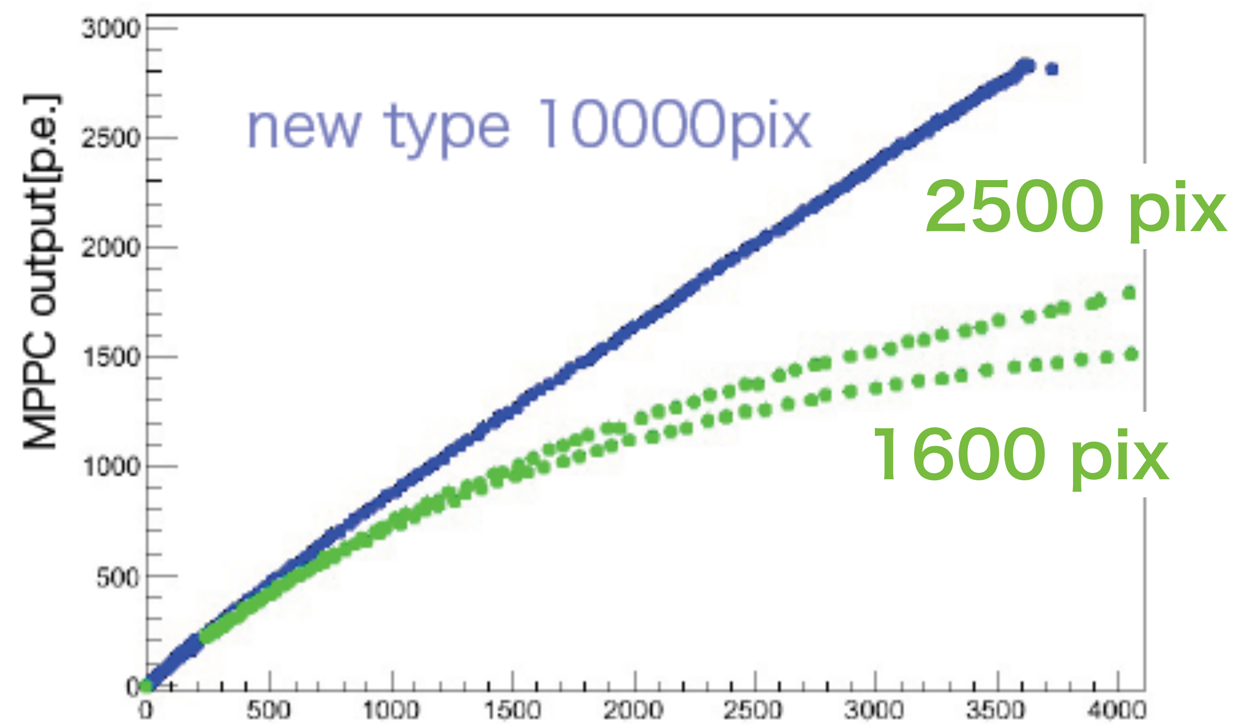
Hamamatsu changed register from polysilicon to metal

Small dead area of new MPPC

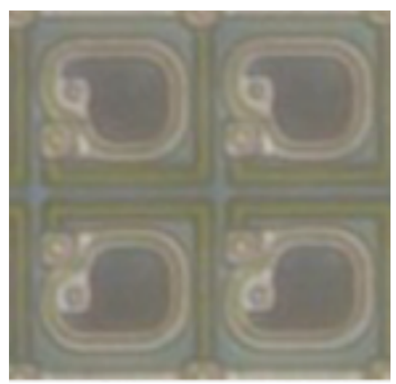
previous
1600 pix MPPC



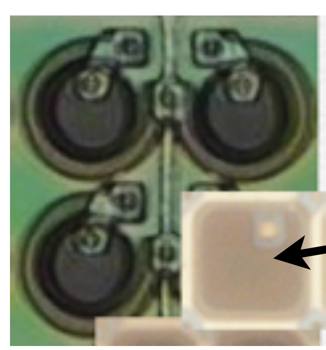
New 1600 pix



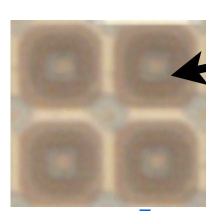
previous
2500 pix MPPC



previous
4400 pix MPPC



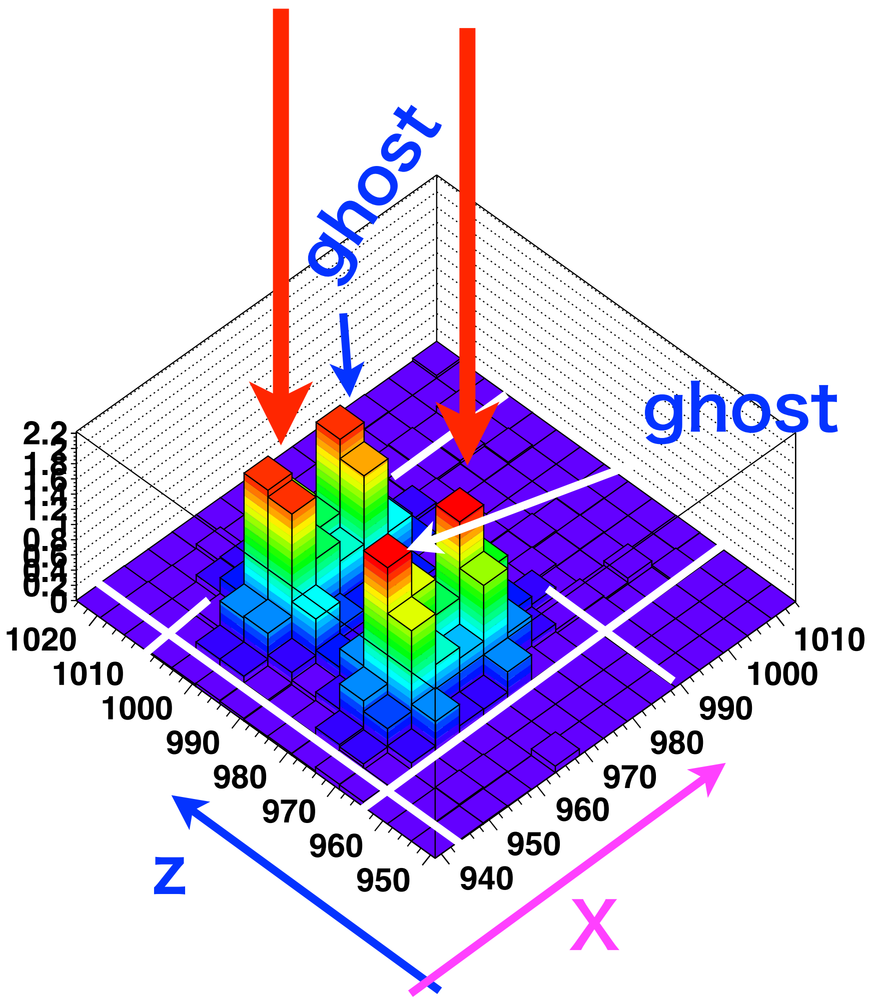
New 4400 pix



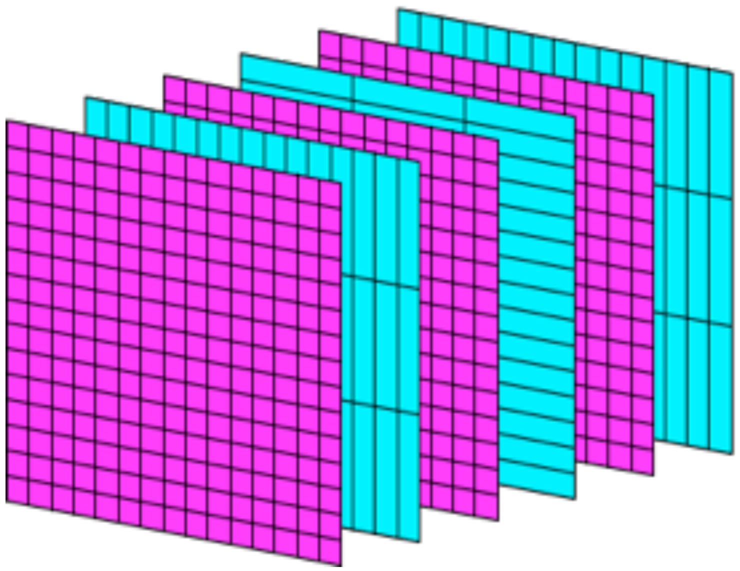
10000 pix with new technology

Low noise, low temp. dependence,

Further optimization (7) :Configuration



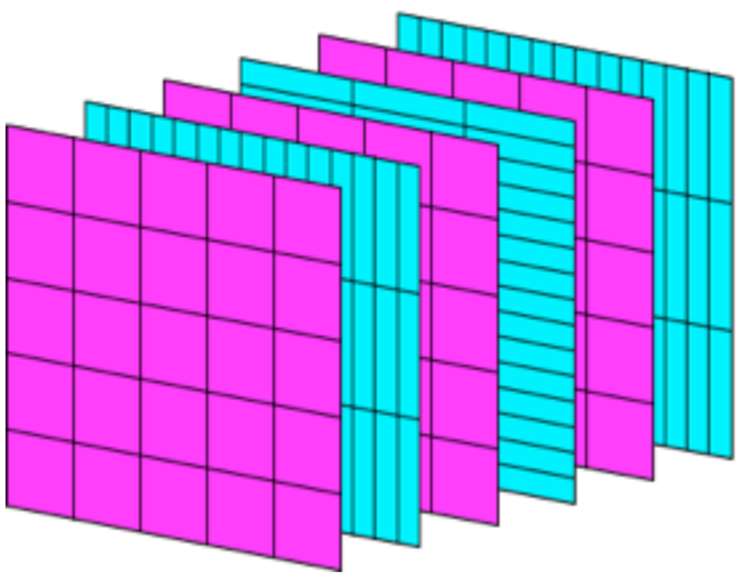
Alternately replace strip layers with 5x5mm^2 tile layers.



def: Alt5x5

Effect 5x5mm^2 tile layer effect is promising
▶ hybrid with Si-layers (next talk)

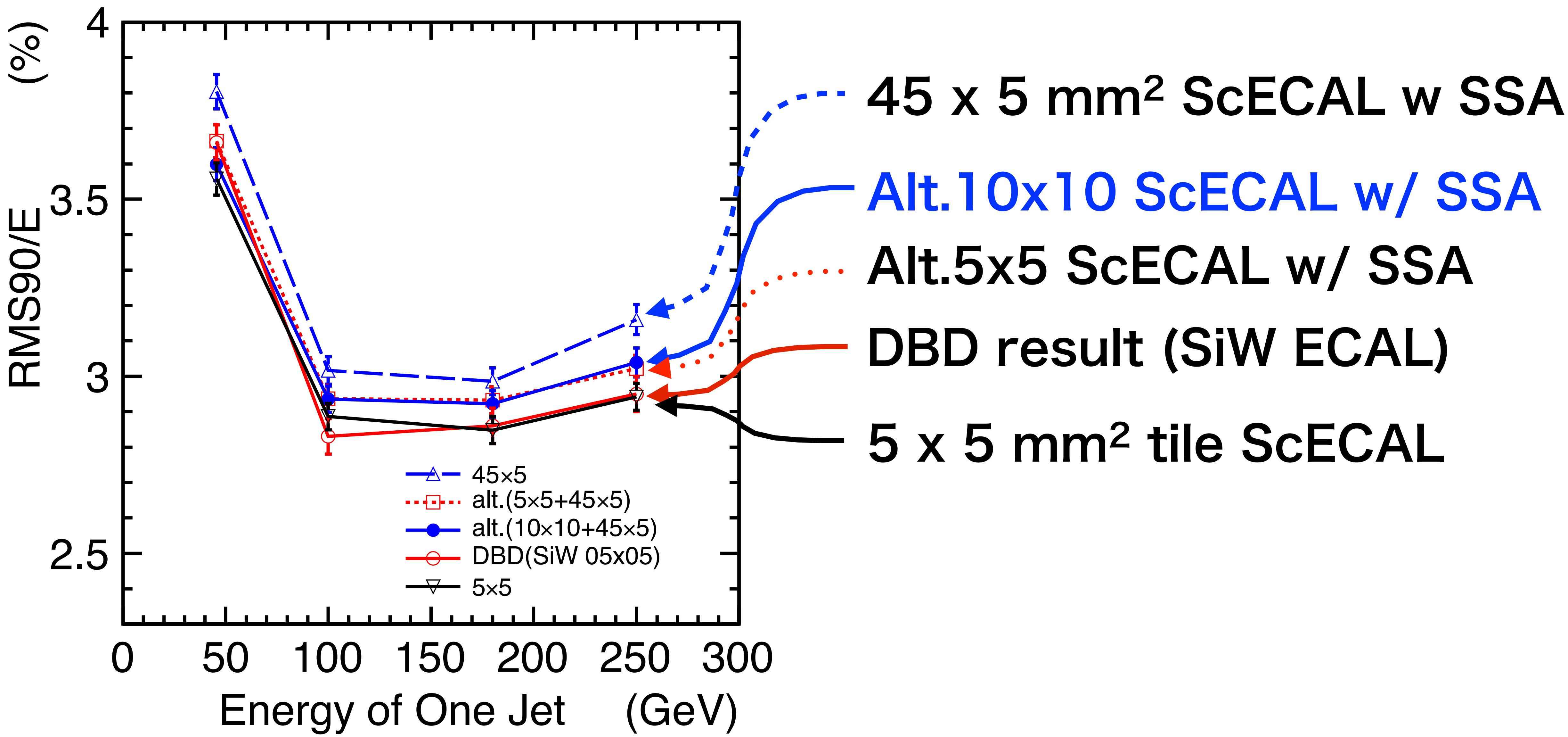
Alternately replace strip layers with large tile layers.



def: Alt10x10, Alt15x15

10x10 or 15x15mm^2 is easy to establish as pure scintillator layers

Further optimization (8) :Configuration



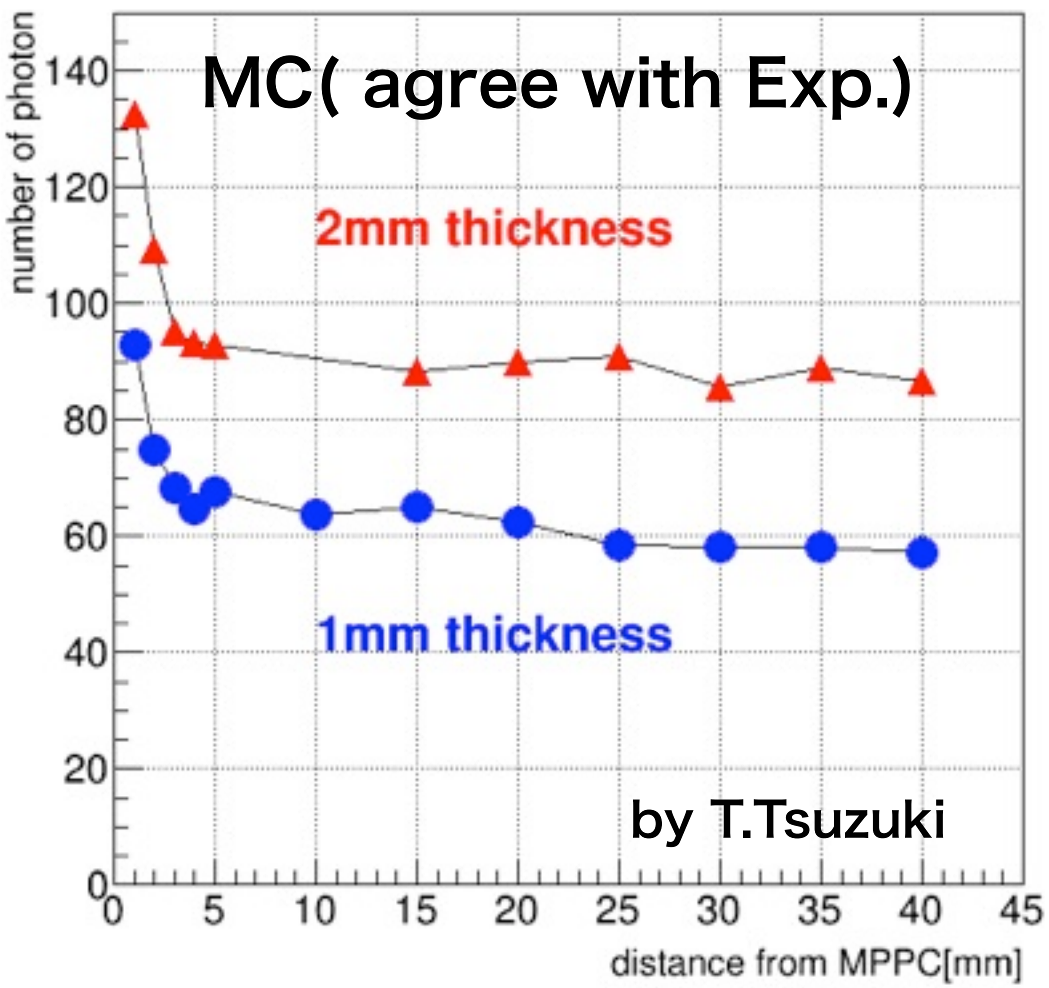
ScECAL alternately replaced strip layers with 10x10 mm² layers has similar energy resolution to 5x5 mm² tile ScECAL (also DBD result with SiW ECAL) at $E_{jet} \leqq$ 100 GeV, only 0.1% degrades at high energy.

Summary

1. We are developing a scintillator strip ECAL for future linear colliders with scintillator strips and SiPMs (MPPC).
2. Good energy resolution for single particles is demonstrated with test beam experiments (FNAL 2009, 3mm thick).
3. Embedded electronics system is being developed with the technological prototype module.
   - Two test beam experiments at DESY.
   - Granularity of 5x5mm^2 has been shown with two layer prototype▶ after the next talk by T. Ogawa.
4. Further optimizations.
   - thickness of scintillator ▶ req. 1.5 times photon yield
   - Sensor shape ▶ study 0.25 x 4 mm^2
   - light collection ▶ tapered wedge is promising ▶next talk by S.Ieki.
   - reflector ▶ current reflector is enough, for easy construction, study on spattering method.
   - MPPC: the number of pixels ▶ HPK succeeded to make 10k pix.
   - configuration of layers ▶ interleaving 10x10mm^2 tile layers way has promising performance. ▶ 12th K.Kotera’s talk.

Further optimization (1) :thickness of Sci.

Thickness 2mm ▶ 1mm,
Module thickness decreases ▶ Cost of magnet is reduced.



- Photon yield is required larger than 7 p.e.),
- Current design 45x5x2mm^3, has ~ 7 p.e. yield at DESY TB
- 1 mm thick scintillator has photon yield factor 2/3

▶ need more p.e.

but before going to 1 mm, we need to evaluate the energy resolution with 1 mm thick scintillators at least with a simulation ▶ On going

* In ILD simulation: 1mm thick OK
photon yield: FNAL TB 14 p.e./MIP: MC agrees Data.

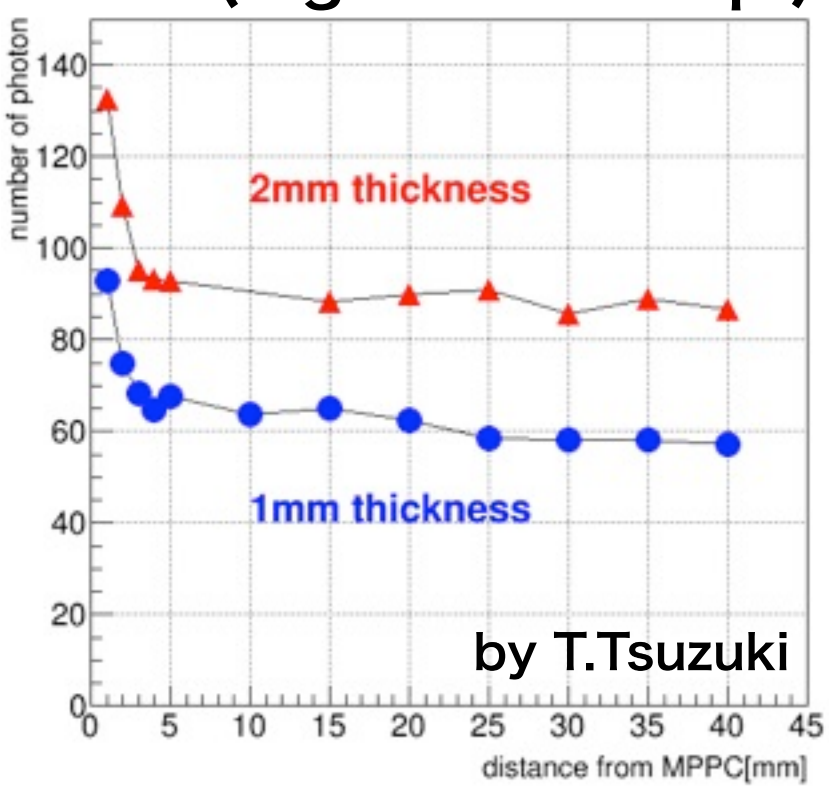
Back up

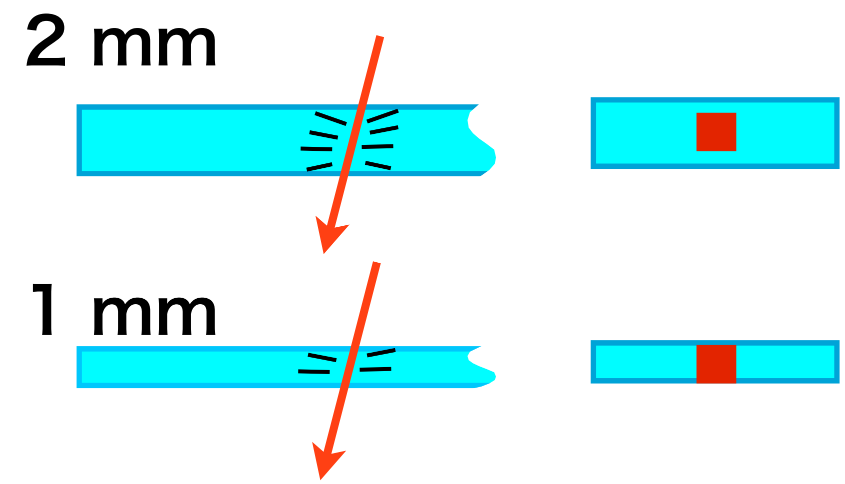
Further optimization (2) :thickness of Sci.

Thickness 2mm ▶ 1mm,

- photon yield (> 7 p.e.),
  current design 45x5x2mm^3, has ~ 7 p.e. yield at DESY TB
  1 mm thick reduces photon yield factor 2/3 ▶ need more p.e.

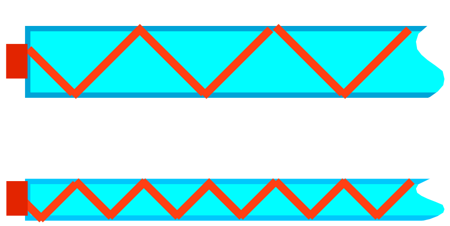
MC(agree with Exp.)





thick(mm)	photon yield@sc	MPPC/ Sci cross section
1	1	: 2
2	2	: 1

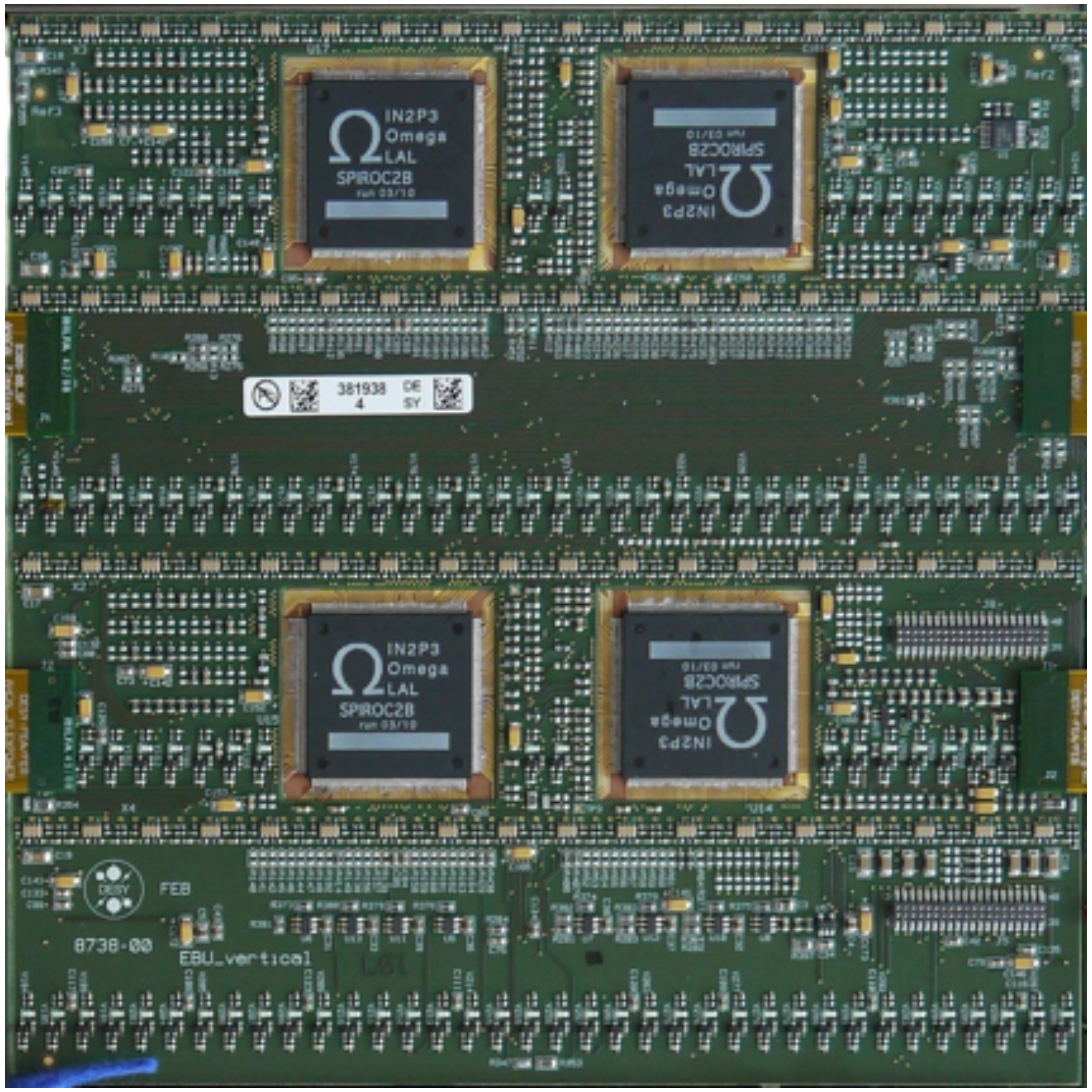
Compensate



: the number of reflection times is doubled in 1mm T scintillator ▶ 2/3 ~ (ref.ratio)^(ref times)

Further optimization (1) :thickness of EBU

Ecal Base board Unit (EBU)

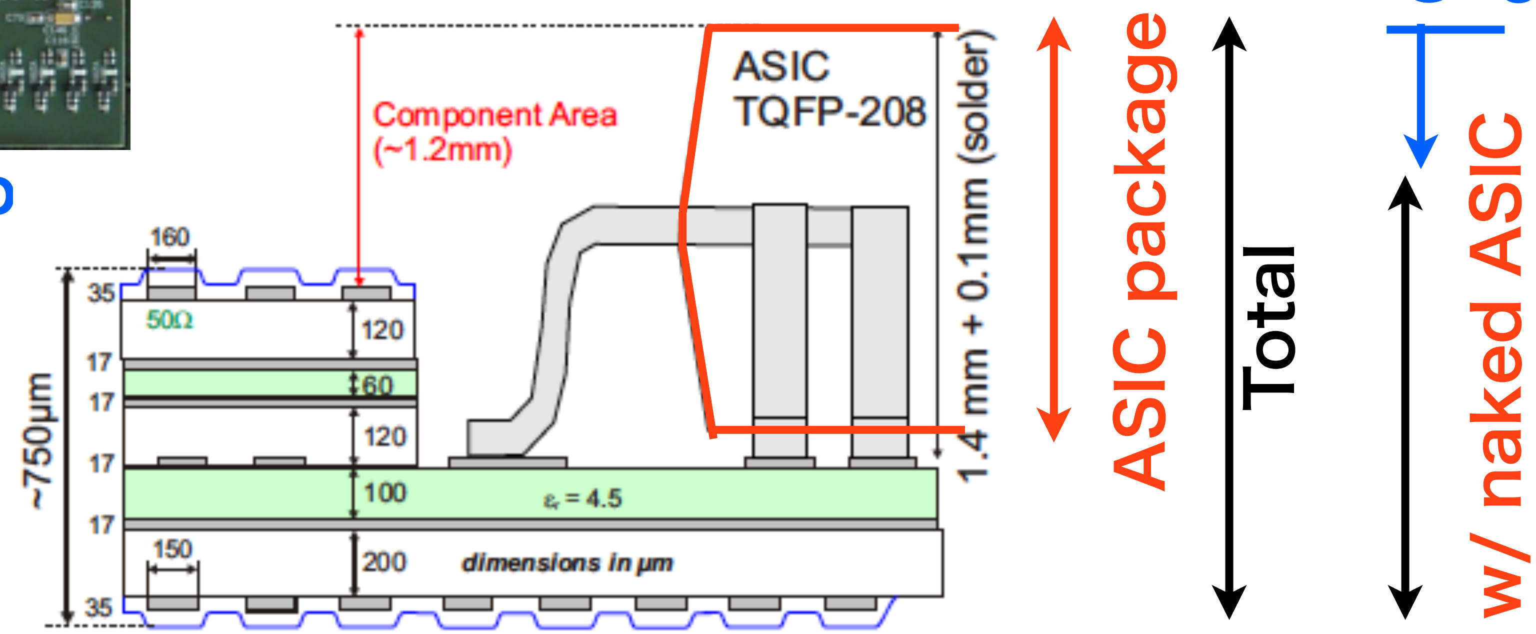


Developed by AHCAL group

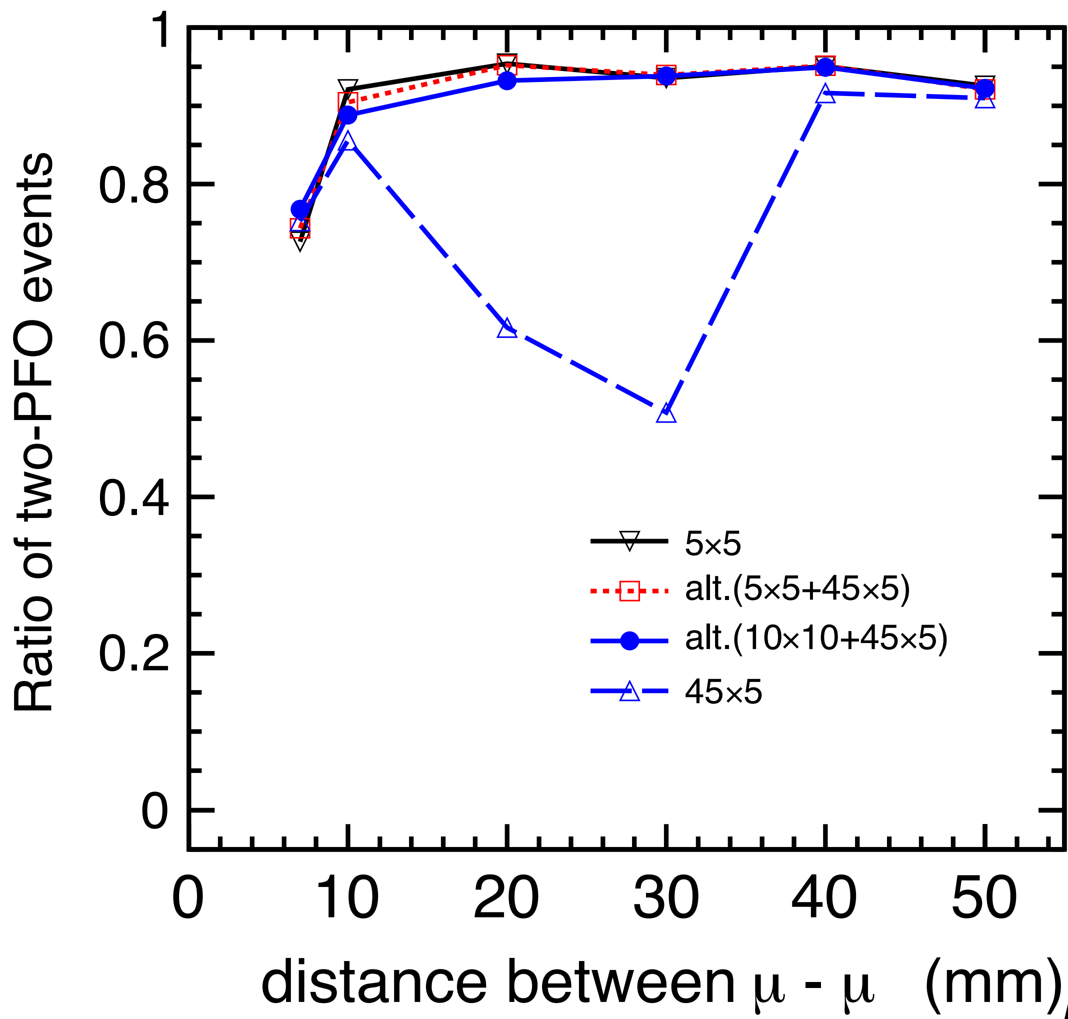
Thinner EBU can reduce thickness of ECAL ▶

Small radius of magnet ▶ Lowcost

1.8 mm ▶ 1.2-1.3 mm req.

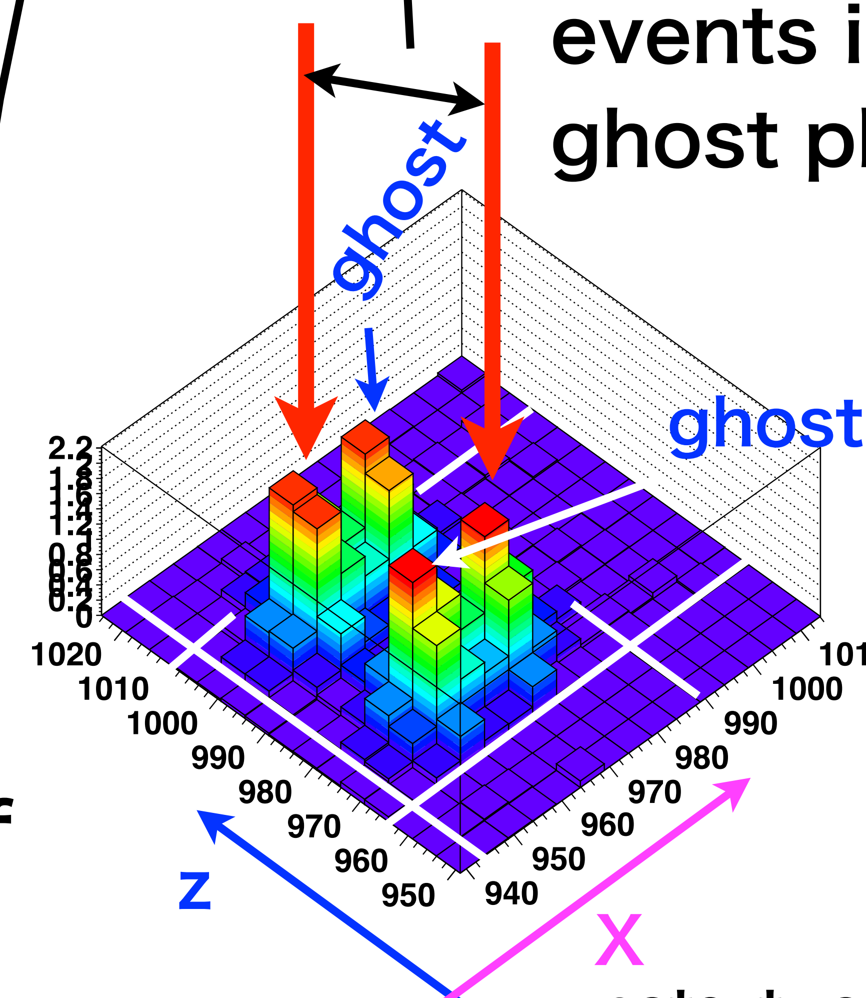


Study on ghost clusters with μ-μ



With 30 mm of distance btw. muons, the number of μ-μ events is significantly reduced with 45x5 mm2 ScECAL with SSA.

We confirmed that the reduction of two muon events is due to the ghost photon

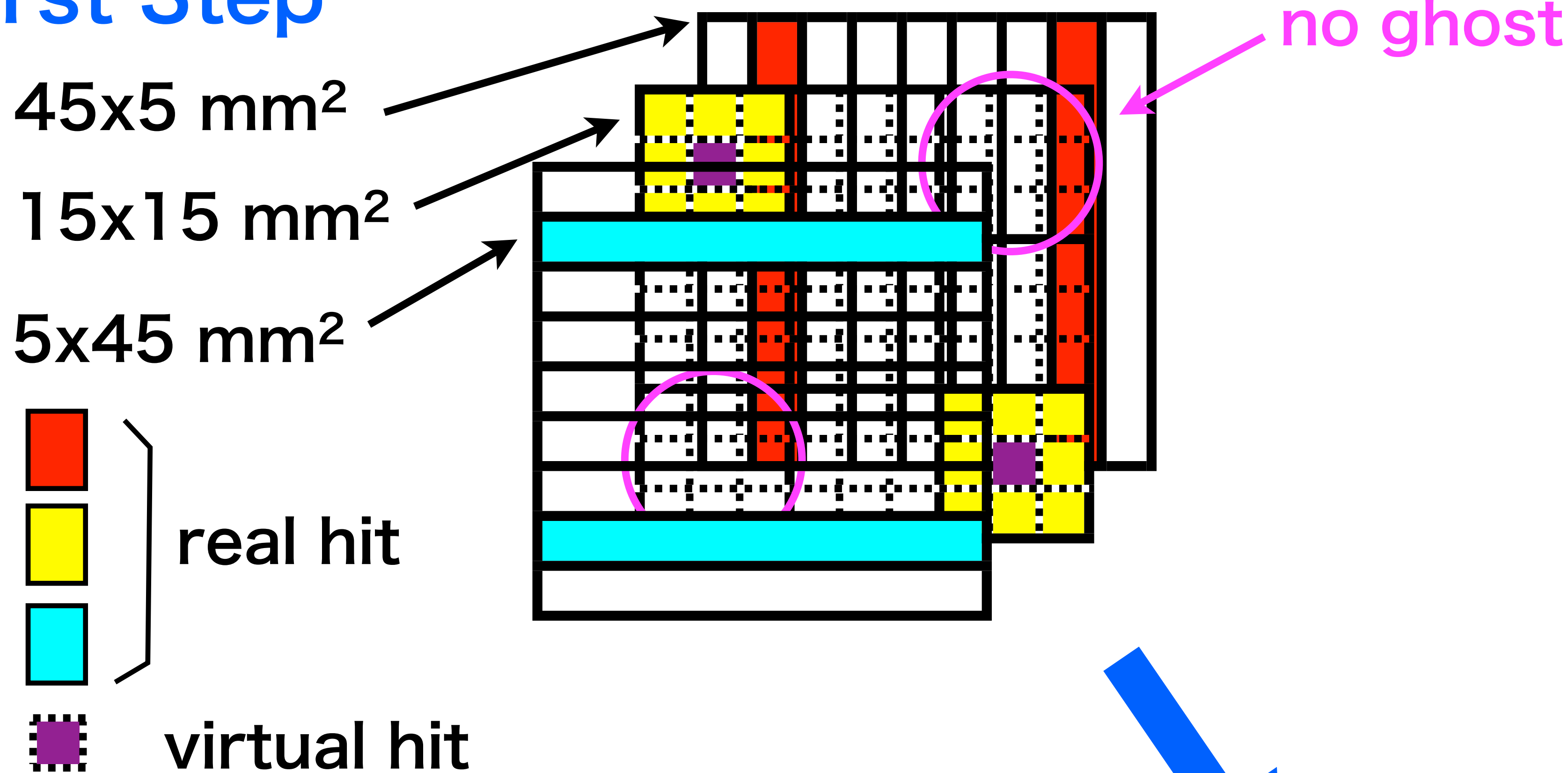


note: two electrons

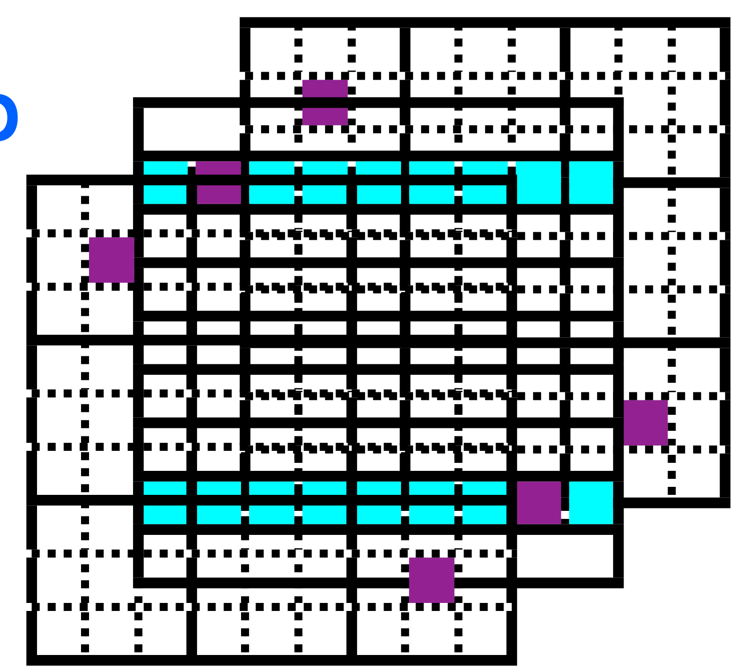
See more detail from slides of 12th my talk.

How to do SSA with large tiles

1st Step

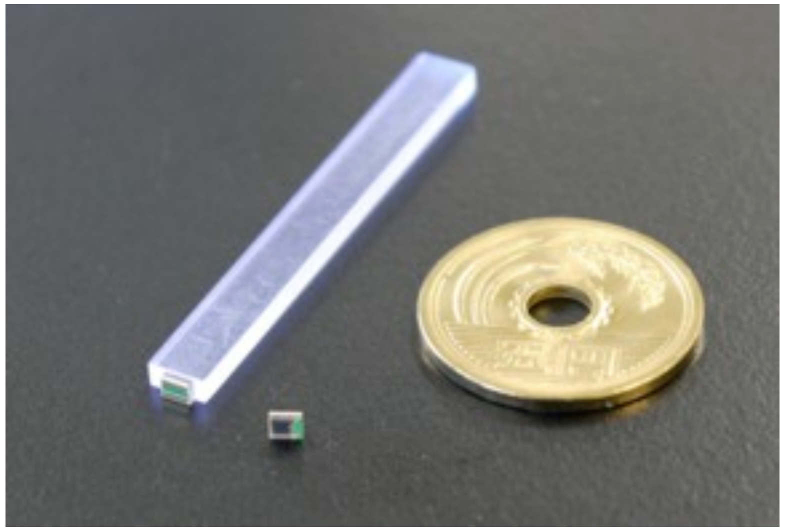


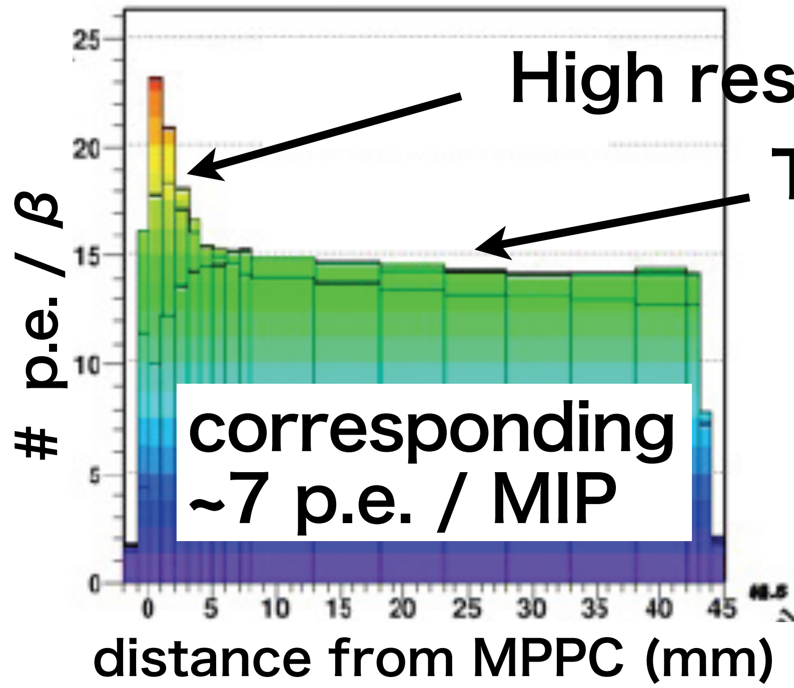
2st Step



a layer is affected by the second nearest layers

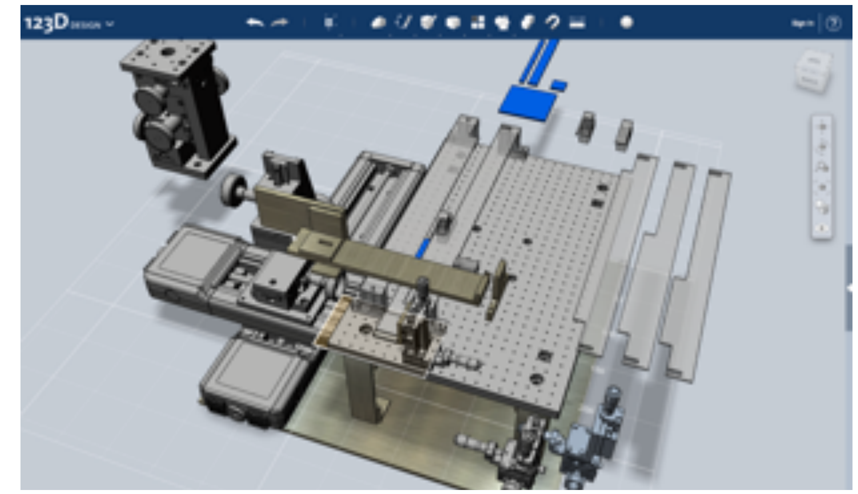
Scintillator/MPPC in near future





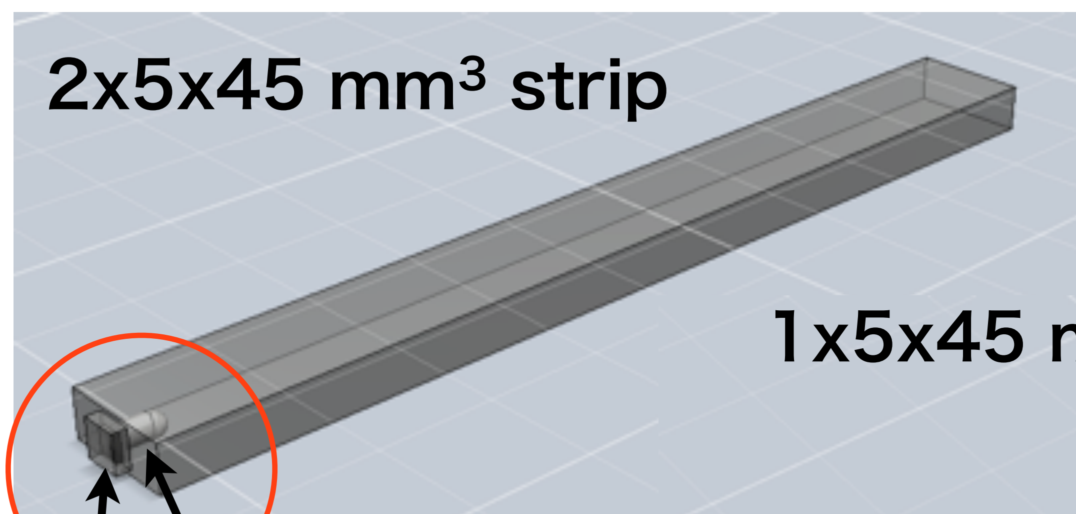
High response in front of MPPC

Total uniformity is OK



meas. system ver,2

Some example of sc/MPPC idea

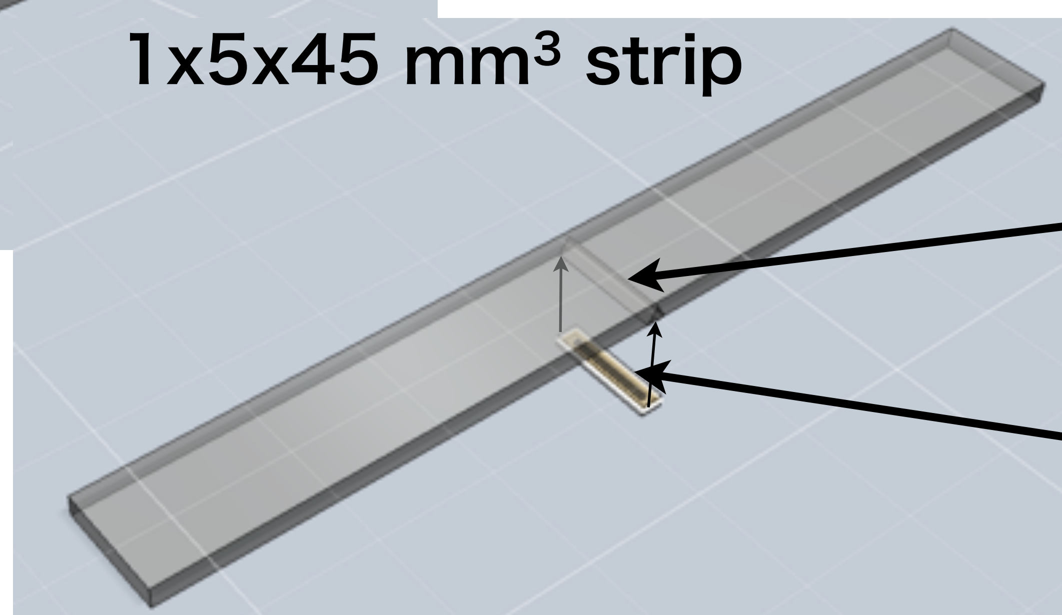


2x5x45 mm^3 strip

clear chip to reduce high response

0.6 mm thick MPPC

New idea by W. Otani

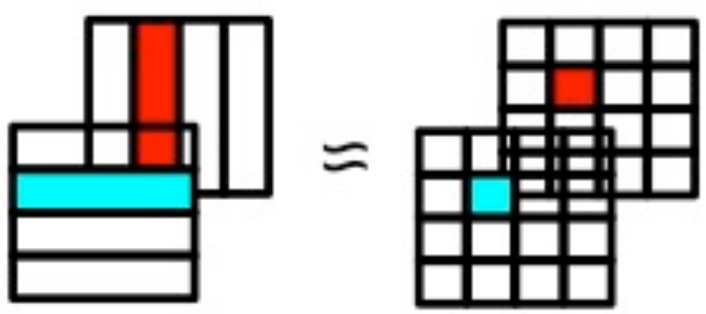


1x5x45 mm^3 strip

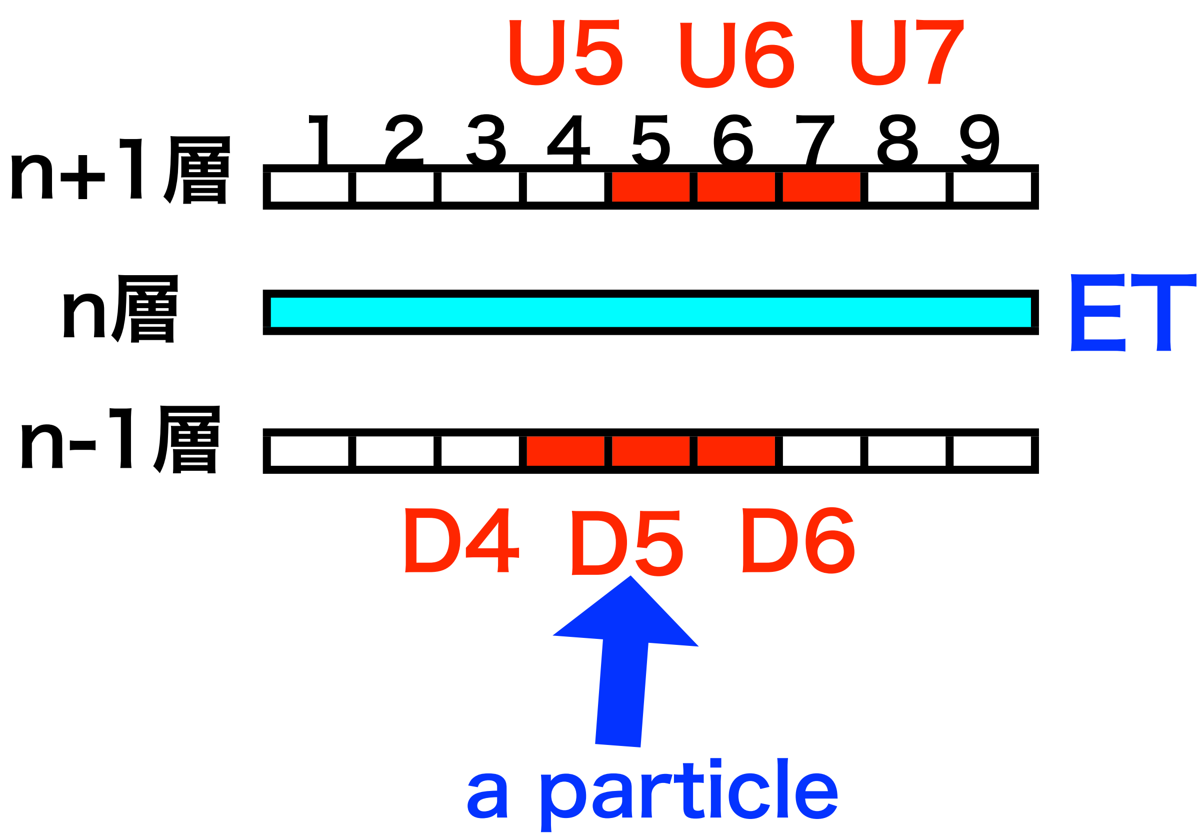
Frosted dimple

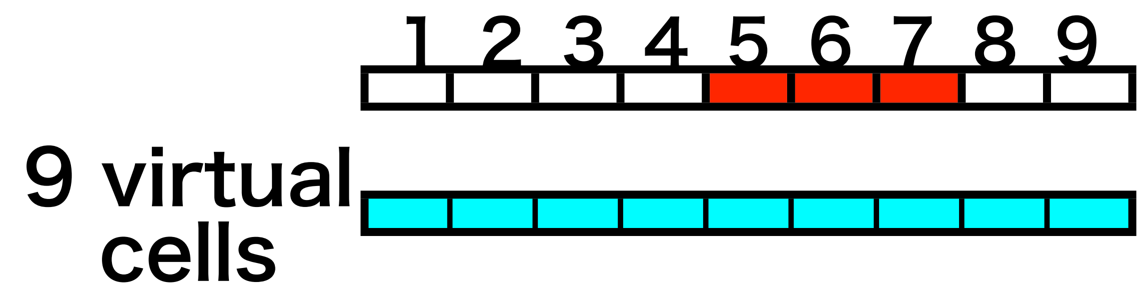
Sensor area
1x1mm^2 ➡ 0.25x4mm^2

Strip Ecal reconstruction with the strip splitting algorithm

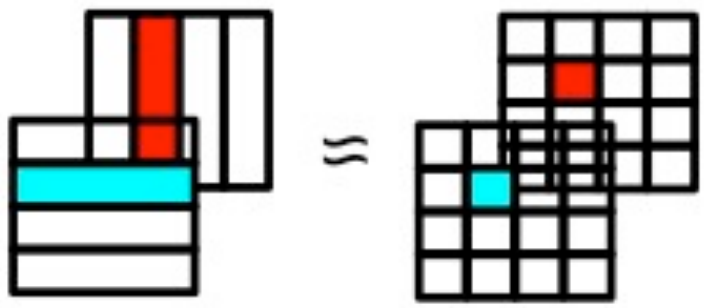


deposited energy on a strip
delivered into virtual square cells

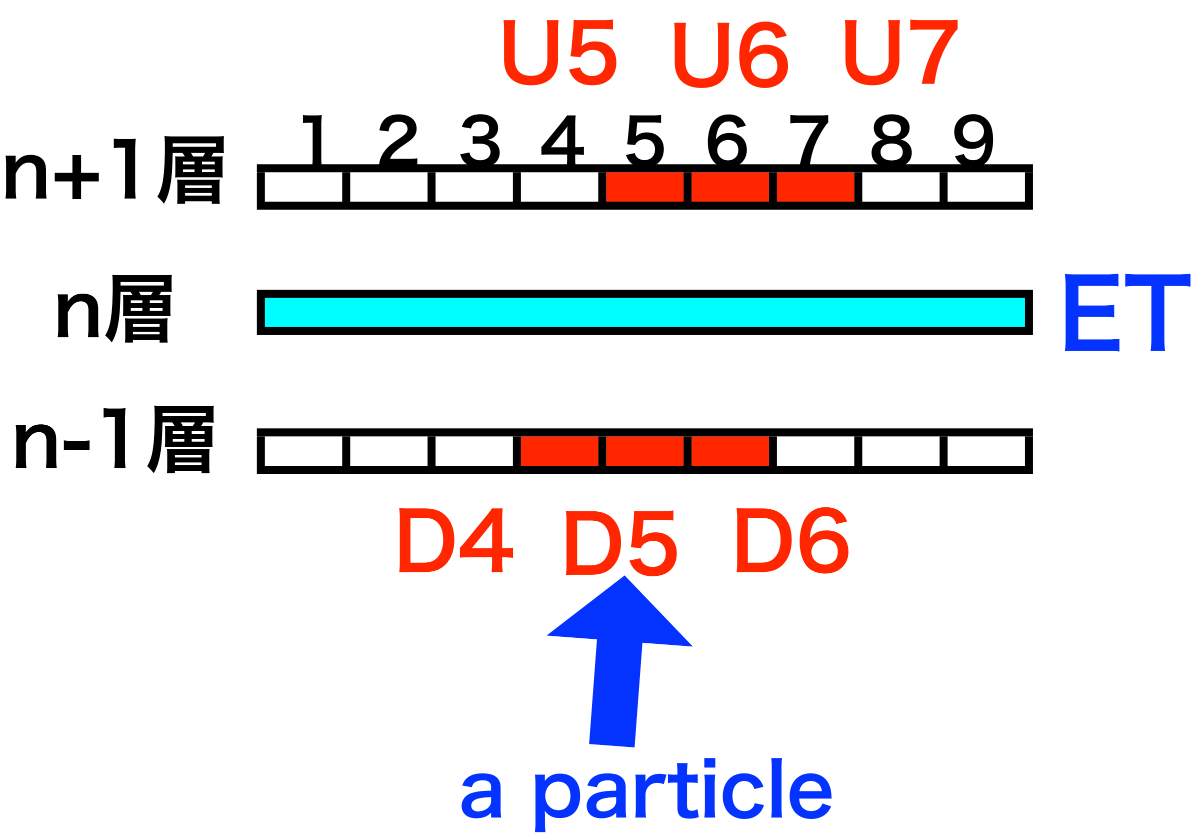


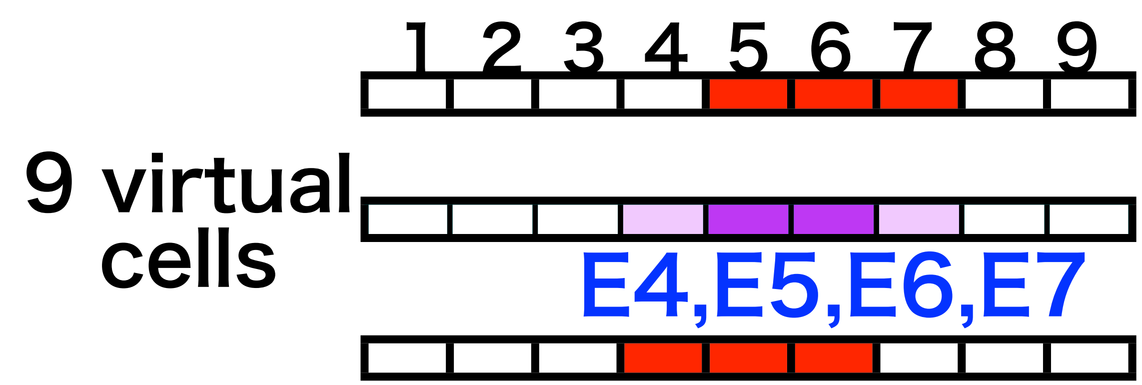


Strip Ecal reconstruction with the strip splitting algorithm



deposited energy on a strip
delivered into virtual square cells





example

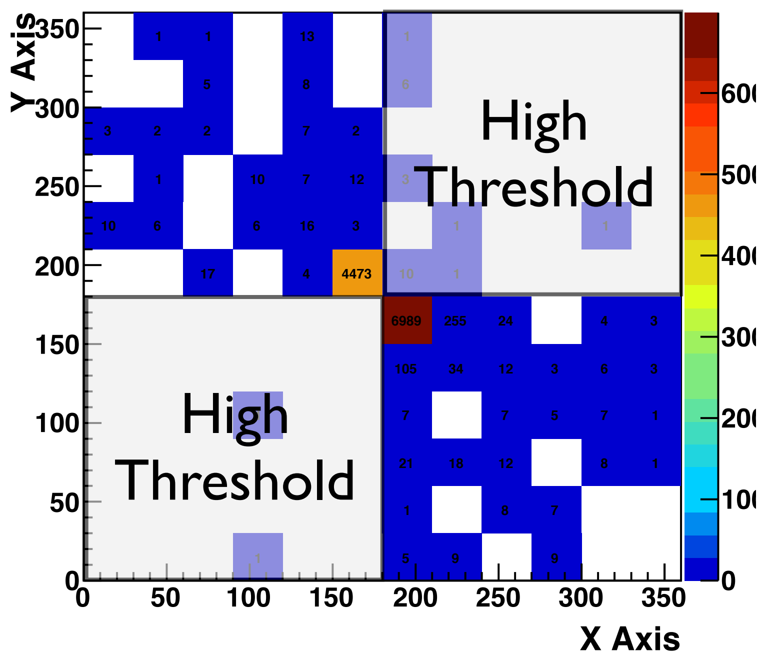
$$E5 = ET \times \frac{U5 + D5}{\sum^{9} Uj + \sum^{9} Dj}$$

positions and energies of all virtual cells are fed into the PandoraPFA program

Synchronization with AHCAL

30 x 30 mm² tiles

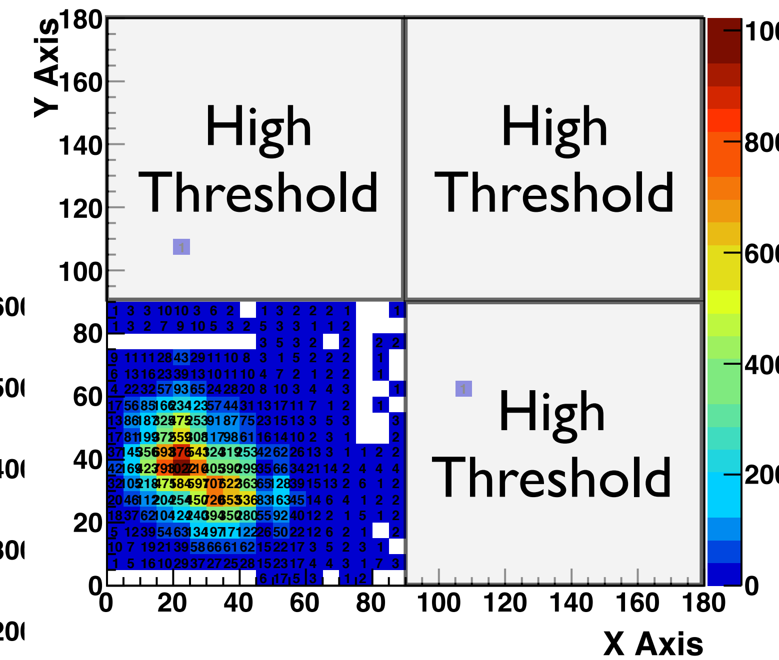
Hit Map of HBU



360mm

45 x 5 mm² strips

Hit Map of EBU

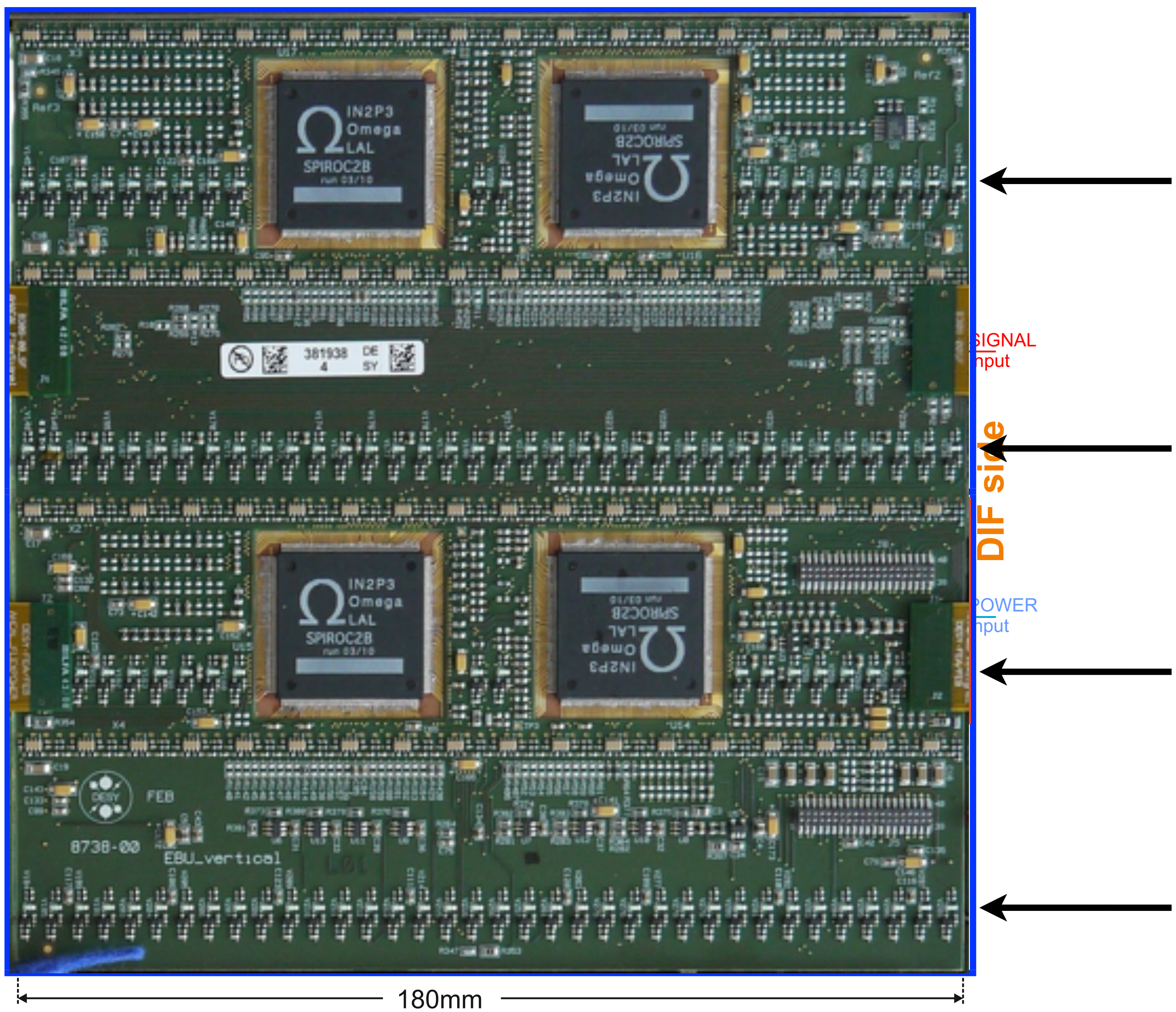


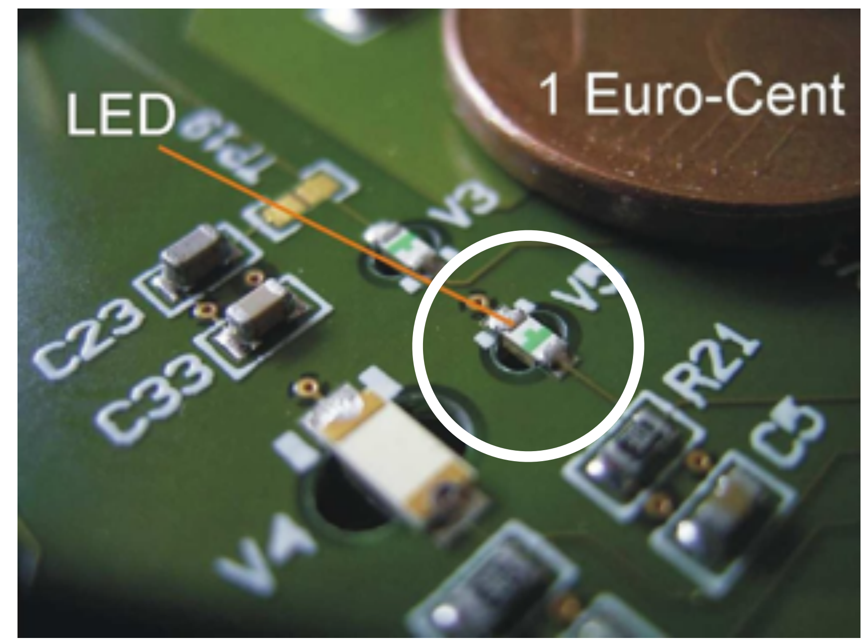
180mm

2-layer-ScECAL

3 GeV electron beams hit two 30 x 30 mm² AHCAL tiles and corresponding 5 x 5 mm² cells on ScECAL reconstructed by using two-layer coincidence of 45 x 5 mm² strips

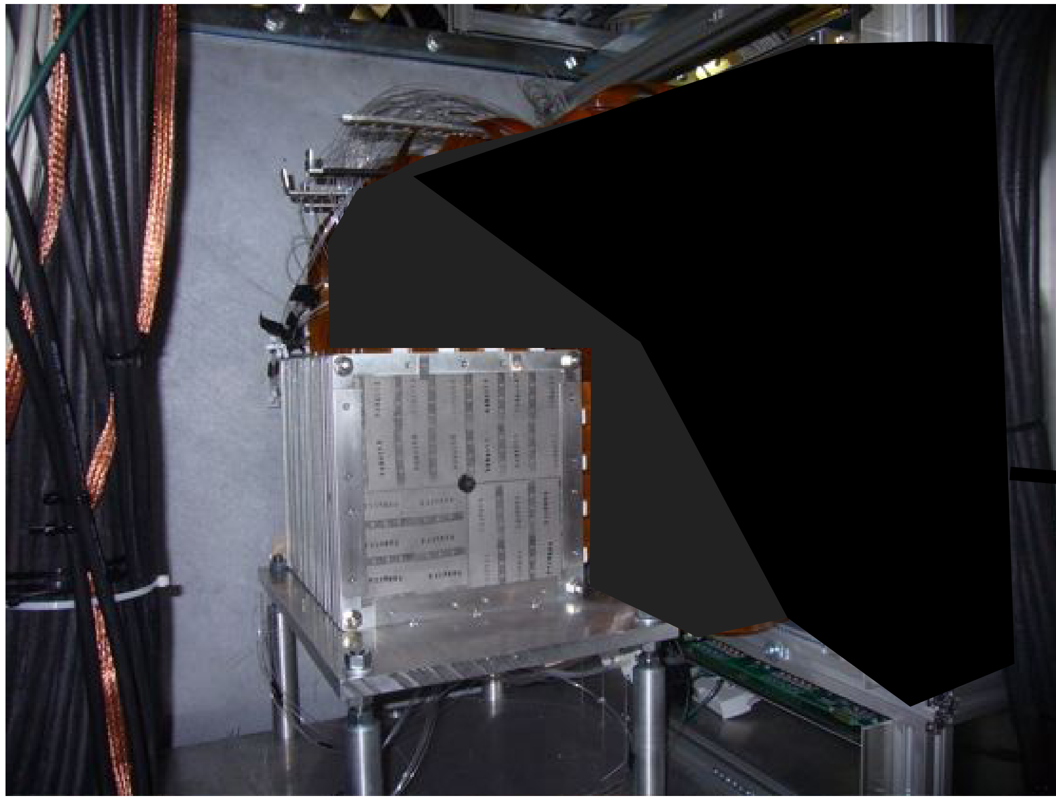
LED lights for gain monitoring



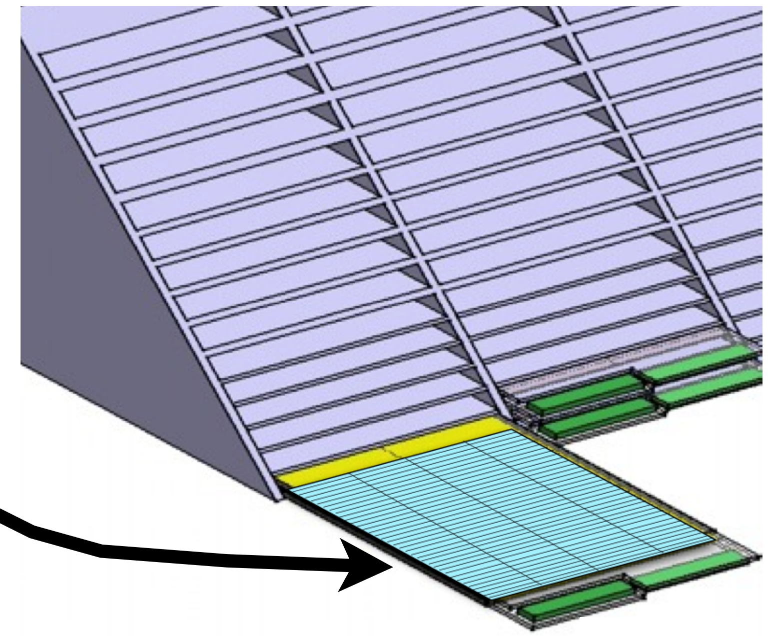


EBU has LEDs for each channel

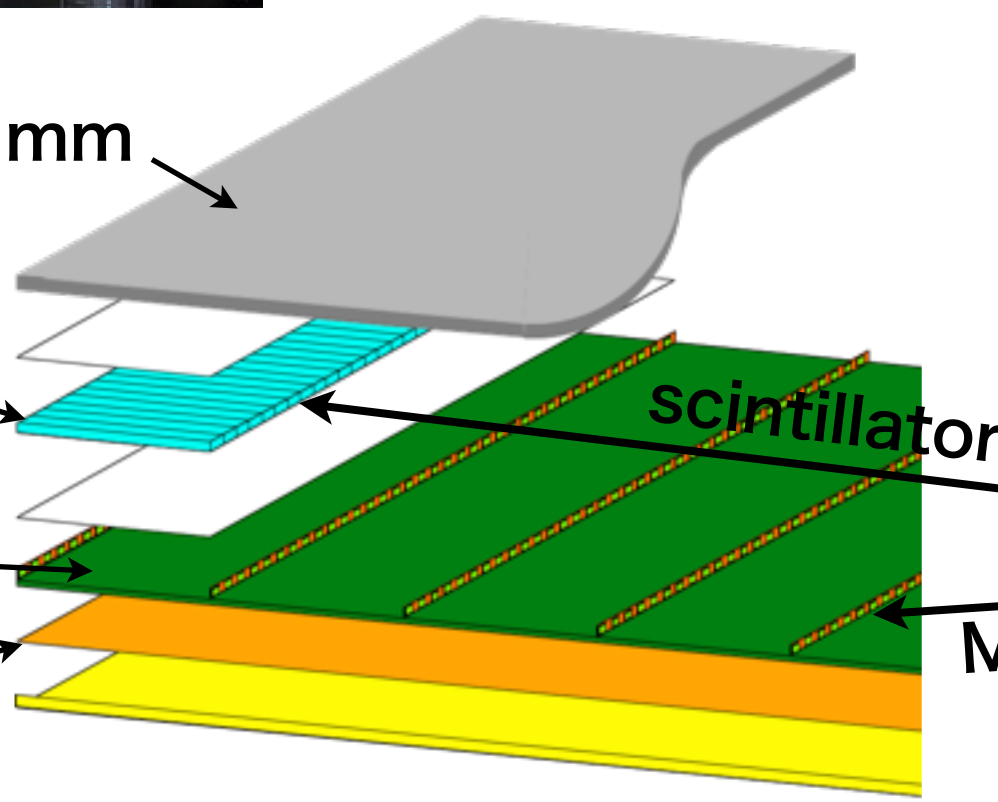
Purpose of technological ScECAL

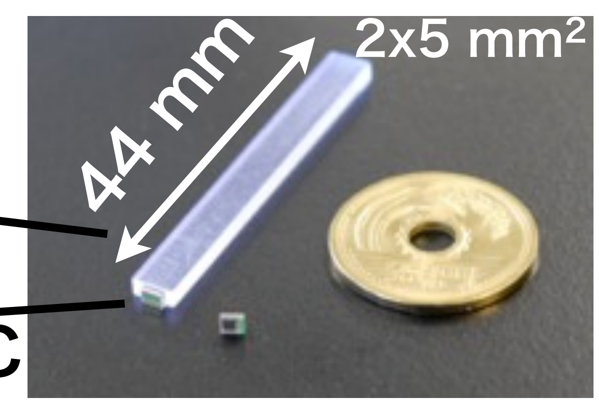


Electronics should be put in between sensor layers for ILD



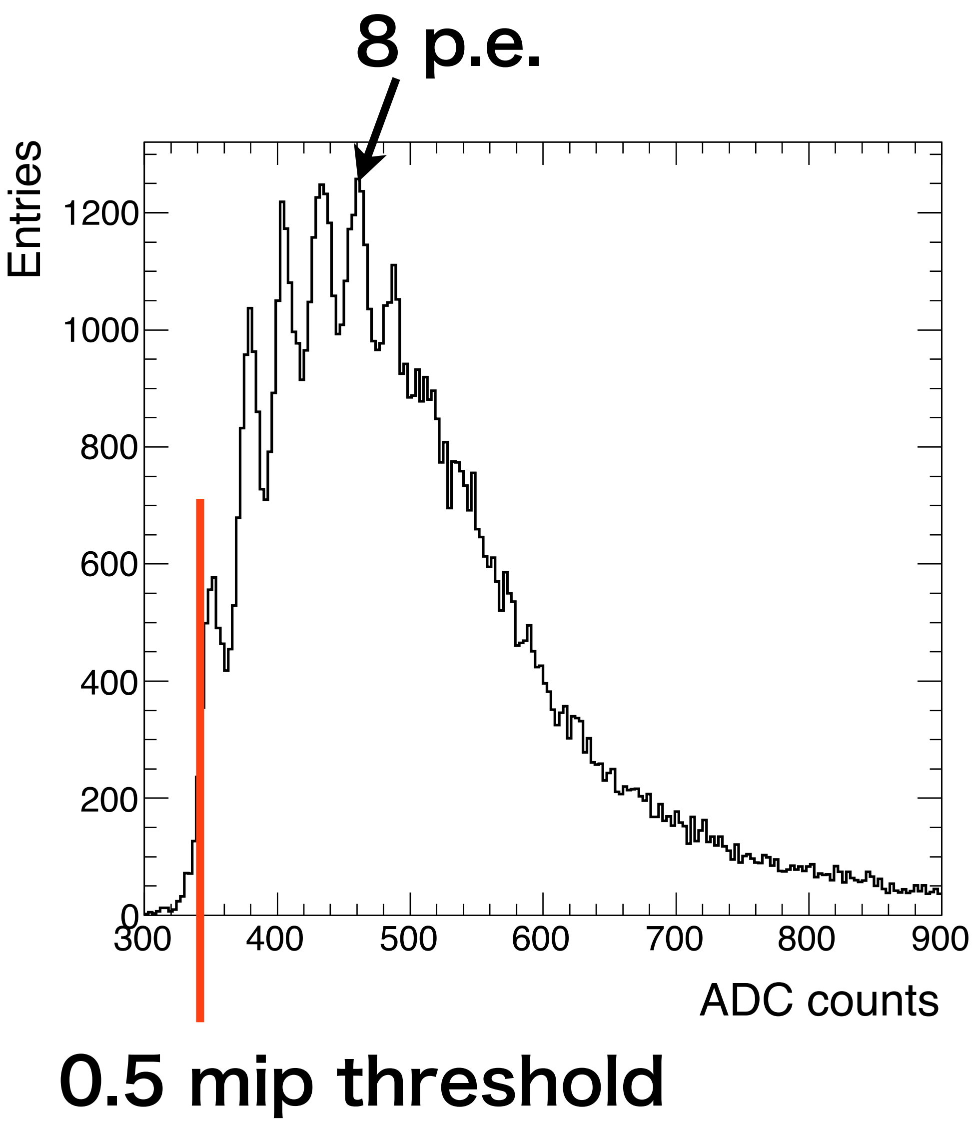
this carton is not true because electronics should cover the sensor





To Show how the technology works well

MIP energy deposit



Energy deposit of mip events on a channel. Clear p.e. peaks can be seen